A Report on NARL activities to

EXTERNAL/PEER REVIEW COMMITTEE

October 2015

NATIONAL ATMOSPHERIC RESEARCH LABORATORY

Department of Space, Govt. of India
Gadanki – 517112, AP

Preamble

During the Indian Middle Atmosphere Program, in early 1980's a need was felt by the Indian atmospheric scientists to have a dedicated facility to probe the earth's middle and upper atmosphere. Thus the idea of realizing a Mesosphere-Stratosphere-Troposphere (MST) radar was mooted. Several Departments under the Government of India, like Department of Space, Department of Science and Technology, Department of Electronics, Council for Scientific and Industrial Research and Department of Environment agreed to fund the project. Indian Space Research Organization (ISRO) was given the responsibility of realizing the project. After an extensive field survey, the Gadanki village near Tirupati was selected due to its low radio noise, topography and proximity to the Sri Venkateswara University for other logistics support.

The design of the then "state-of-the art" MST radar was finalized in 1988, with 1024 Yagi-Uda antennas arranged over an area of 130 m X 130 m operating at 53 MHz with a peak power of 2.5 MW. The radar was realized indigenously in collaboration with SAMEER, Mumbai and was made operational first in the ST mode in 1991 and in the full MST mode in 1993. This facility was registered as the National MST Radar Facility (NMRF), an autonomous scientific society under Department of Space, Government of India in January 1993.

Over the time various other complimentary facilities were added such as the Rayleigh Lidar and Lower Atmospheric Wind Profiler provided by the then Communications Research Laboratory, Tokyo, Japan and the activities of NMRF have significantly increased in scientific utilization of the facilities. NMRF also started taking major scientific and technical initiatives in diverse areas of atmospheric science research in the country. Considering these facts and to give wider scope, the name of the facility was changed by the Governing Council from NMRF to the National Atmospheric Research Laboratory (NARL) in September 2005.

During 2007 scientific and technical groups were formed, gap areas were identified, additional scientific disciplines were added with suitable augmentation of instruments and manpower. Today NARL is a unique laboratory in the country with a large number of observational facilities along with modelling activities to study the atmosphere from surface layer to the top of the ionosphere, guides PhD students and publishes high quality research papers in reputed scientific journals.

Our Vision:

Developing capability to predict the behavior of the atmosphere through observation and modeling

Our Mission is to strengthen ..

Former Directors

Prof. P. Balarama Rao

1990 - 1998

NMRF was formed with Prof. P. Balarama Rao, an expert in Space Physics, Radio wave Propagation and Radar Systems, as the Founder Director. The expansion of the facilities with Lidar and Lower atmospheric wind profiler took place during this period which opened up new research activities. Various technological improvements for MST radar started during his period catching up the digital technology revolution. The 8th International MST Radar workshop was conducted under his leadership in 1997. Currently he is an honorary visiting Professor at the National Remote Sensing Centre, Hyderabad.

Dr. A. R. Jain

1998 – 2002

Scientific research in troposphere and boundary layer was strengthened during the period 1998-2002 under the leadership of Dr. A. R. Jain who is an expert in Space Physics, Radio wave Propagation, and Radar Systems. Initiation of Automatic weather stations and balloon launch activities, up gradation of signal processing and radar control systems of MST radar happened during his period. Currently he is an honorary visiting Professor at the National Physical Laboratory, New Delhi.

Prof. D. Narayana Rao

2003– 2007

The renaming of NMRF to NARL happened during the tenure of Prof. D. Narayana Rao, who is an expert in Radio wave propagation studies and Radar Meteorology. Indigenous development of SODAR, Boundary Layer Lidar, regular launching of GPS Radiosonde and initiation of L-Band Lower Atmospheric Wind Profiler took place during his tenure. The 11th International MST Radar workshop was conducted under his leadership in 2006. Currently he is Director, Research at the SRM University, Chennai.

NARL Governing Council

Shri. A.S. Kiran Kumar Chairman, ISRO/ Secretary, DOS ISRO Headquarters, Bangalore	Chairman
Prof. U. R. Rao Chairman, ADCOS ISRO Headquarters, Bangalore	Member
Dr. George Joseph Chairman NARL Scientific Advisory Committee	”
Representative Department of Science and Technology Government of India	”
Representative Ministry of Earth Sciences Government of India	”
Representative Council of Scientific & Industrial Research	”
Additional Secretary/Joint Secretary, Department of Space, Bangalore	”
Joint Secretary (Finance) Department of Space, Bangalore	”
Scientific Secretary ISRO Headquarters, Bangalore	”
Prof. A. Jayaraman Director, NARL	Member Secretary

Scientific Advisory Committee

Prof. George Joseph Honorary Distinguished Professor, ISRO	Chairman
Dr. B.M. Reddy INSA Honorary Scientist, NGRI, Hyderabad	Alt. Chairman
Prof. P. C. Agrawal, Prof of Physics, Mumbai Univ., Mumbai	Member
Prof. P. B. Rao Visiting Professor, NRSC, Hyderabad	”
Director, NRSC, Hyderabad	”
Director, Indian Institute of Tropical Meteorology, Pune	”
Director, ISTRAC, Bangalore	”
Director, SPL. Thiruvananthapuram	”
Prof. G.S. Bhat , CAOS, IISc., Bangalore	”
Prof. Shyam Lal, Senior Professor, PRL, Ahmedabad	”
Prof. O.P. Sharma Centre for Atmospheric Sciences, IIT, Delhi	”
Dr. P. K. Pal, AOSG, SAC, Ahmedabad	”
Prof. S. K. Satheesh, CAOS, IISc., Bangalore	”
PD, SSO, ISRO HQ, Bangalore	”
Prof. A. Jayaraman Director, NARL, Gadanki	Member-Secretary

Contents

1. Overview 1

2. Staff (Scientific & Technical / Administrative) profile 5

3. Budget Profile 7

4. Research Facilities 9

5. Radar and Lidar Utilization 23

6. Infrastructure Developments 25

7. Scientific and Technical Accomplishments and Way Forward 35

   7.1 Radar Applications and Development Group 37
   7.2 Ionospheric and Space Physics Group 45
   7.3 Atmospheric Structure and Dynamics Group 53
   7.4 Cloud and Convective Systems Group 61
   7.5 Aerosols Radiation and Trace Gases Group 69
   7.6 Weather and Climate Research Group 75
   7.7 Computers and Data Management Group 83
   7.8 LIDAR Project 89
   7.9 Advanced Space-borne Instrument Development 93

8. Publications 99

9. Awards and International Recognitions 101

10. National and International Collaborations 105

11. In-house Project Training 109

12. Data Archival and Dissemination 111

13. ISRO Sponsored Research (RESPOND) 113

14. Workshops/Conferences/Schools Organized 115

15. Public Outreach 119

Annexure (Publications List) 121

1. Overview

NARL specializes in studying the Earth's atmosphere through technology development, observation and modeling. It had its humble beginning in 1992 as the National Mesosphere-Stratosphere-Troposphere (MST) Radar Facility. Over the years several complementary techniques such as Rayleigh/Mie lidars, wind profilers have been added. NARL is administered by a Governing Council with Secretary, Department of Space, Govt of India as the Chairman and Director, NARL as member secretary. The Governing Council sets broad policy guidelines for NARL. A Scientific Advisory Committee consisting of eminent scientists in the field of atmospheric science monitors the research activities and progress of NARL and provides future directions. Over the years the staff strength has been increasing and at present there are 48 Scientific and Technical and 16 administrative staff apart from 22 research and Post-Doctoral fellows. The annual budget has been growing from a modest amount of about 20 million Rupees per year in early 2000's to 280 million Rupees for the current financial year.

Currently there are more than 35 observational facilities which are in regular operation at NARL which includes MST Radar, Rayleigh lidar, Rayleigh Doppler lidar, Mie lidar, L-Band wind profilers, ionosonde, HF radar, air-glow imager, daily radiosonde launches, weather station, radiation, aerosol and trace gases measuring instruments along with a high performance computing system. NARL has a mandate of providing the MST radar and Rayleigh lidar data to any scientific user group in the country as well as abroad. On an average the radar is operated for about 3000 hours per year and the Rayleigh lidar for about 190 nights per year and the data are archived for dissemination to the user community. Over the years the laboratory and office space have been systematically augmented to house the experimental facilities and personnel.

The research and development activities are carried out by seven groups viz., Radar Development and Application Group (RADG); Ionosphere and Space Physics Group (ISPG); Atmospheric Structure and Dynamics Group (ASDG); Clouds and Convective System Group (CCSG); Aerosols Radiation and Trace Gases research Group (ARTG); Weather and Climate Research Group (WCRG); Computers and Data Management Group (CDMG) and are supported by the Civil and Maintenance Department and the Administration section. There are also two independent projects viz., the LIDAR project and Space-borne instrumentation development.

The Radar Development and Application Group (RADG) is involved in the indigenous development of a varieties of radars for atmospheric studies and also has the responsibility of regular operation and day to day maintenance of the existing radars. The group also support by providing wind profiles measured using the MST radar to the Satish Dawan Space Centre (SDSC) at Sriharikota for wind biasing the launch vehicles. So far NARL supported 44

launches from SDSC which includes Chandrayaan-1, Mangalyaan-1, GSLV MKIII, GSLV, PSLV, and ASLV launches.RADG has developed two lower atmospheric wind profiling (LAWP) radars, operating at 1280 MHz, for observing the lower atmosphere dynamics. These radars, developed indigenously and first of its kind in India, are designed with innovative technological features that include simplified active aperture, passive calibration-free Butler Beam Forming Network (BFN), pulse compression scheme and direct IF digital receiver.RADG has also developed a new 30-MHz radar for dedicated probing of ionosphere and meteor showers. The system comprises 160 numbers of 14° tilted two-element Yagi antennas arranged in a 20x8 matrix over an area of 112m x 56m. A total peak power of 150 kW is generated by 20 numbers of 7.5- kW solid-state TR Modules. The group is currently involved in the up-gradation of the existing 1024-element Indian MST radar into a full-fledged active phased array system. The up gradation of all the 1024-elements is at very advanced stage of implementation and will be completed in a few months' time from now. In the coming years the group has a plan to develop an E-Scan Doppler Weather radar and a low cost 445 MHz Spaced antenna wind profiler.

The major objectives of the Ionospheric and Space Physics Group (ISPG) are to understand the physics of plasma irregularities in the low latitude ionosphere through observation, analysis, and numerical simulation with specific focus to understand the composition, energetics, and dynamics of the ionosphere and to study the plasma bubbles that are detrimental for satellite based communication and navigation applications. Some of the important findings are reported in the following sections. The group has recently developed and installed an advanced mesosphere lower thermosphere photometer capable of taking measurements of OH (840 and 846 nm lines), O2 (866 and 868 nm lines), O (1D) airglow emissions which provides simultaneous information on mesospheric temperatures and behavior of the thermosphere-ionosphere system. The group has also established a network of 8 GPS/GNSS/IRNSS receivers for high resolution imaging of TEC/scintillations. The group has plan to augment the active array MST radar with incoherent scatter capability to measure electron density, ion composition, ion and electron temperatures, ExB drifts and meridional wind. Also it is proposed to make high resolution measurements of TEC and scintillation using GNSS network along latitude and longitude belts. It is proposed to augment the SAMI3 model with GCM and India specific data assimilative schemes.

The major objectives of the Atmospheric Structure and Dynamics Group (ASDG) are to study the tropospheric and lower stratospheric structure and dynamics, study of generation as well as the vertical propagation of atmospheric gravity waves, structure and dynamics of the mesosphere and lower thermosphere etc. ASDG also has the major responsibility of operating the Rayleigh temperature lidar and the Rayleigh Doppler Lidar apart from daily launching of the GPS balloon sonde. The major research findings and accomplishments are presented in the following sections. In the coming years the group will

be developing a DIfferential Absorption Lidar (DIAL) for measuring Ozone concentrations for the study of troposphere-stratosphere exchange process over the tropics.

The major objectives of the Clouds and Convective System Group (CCSG) are to study the microphysics and dynamics of clouds, precipitation and other high impact weather systems, boundary layer processes and their relation to the generation of convection, monsoon dynamics in general, active and break spells in particular. The major research findings during the reporting year are presented in the following sections. One important research highlight in the recent year is an extensive and comprehensive evaluation of five widely used multi-satellite precipitation estimates over India using high-resolution gridded rainfall dataset as reference. This study not only quantified detection and accuracy metrics, but also evaluated the variability of rainfall over different temporal scales. One of the major activities targeted for the coming year is installation and commissioning of an X-Band polarimetric radar being developed by ISTRAC, Bangalore.

The major objectives of the Aerosols Radiation and Trace Gases research Group (ARTG) is to study aerosols, trace gases and radiation, role of meteorology in controlling the surface concentrations, vertical profile and aerosol chemistry, estimation of radiative forcing efficiency for natural and anthropogenic aerosols, aerosol cloud interaction etc. ARTG also has the responsibility of maintaining the Climate Observatory established at Gadanki and make regular observations of essential climate variables such as the concentrations of aerosols, carbon dioxide, black carbon, ozone, oxides of nitrogen, and radiation parameters such as the direct solar radiation, global radiation etc. The major research findings during the reporting year are presented in the following sections. One of the major highlights during recent time is joint experiments with NASA LaRC scientists in the summer of 2014 and 2015 involving simultaneous balloon and lidar experiments from Gadanki and other locations in India to study the Asian Tropospheric Aerosol Layer. In the coming years monitoring of methane, volatile organic compounds and organic aerosols will be included as a part of regular measurements from the climate observatory. An analyzer to monitor hydroxyl radical will be developed in-house at NARL. A full-fledged atmospheric chemistry laboratory will be established with facility for analytical chemistry, smog chambers and cloud chambers.

The Weather and Climate Research Group (WCRG) activity is focused on identifying the physical mechanisms associated with atmospheric convections, its diurnal variation and weather and climate forecasting through observations and modeling. WCRG also issues real time forecast to SDSC, SHAR during launch operations. The major research findings are presented in the following sections. In addition to weather and climate modeling the group initiated air quality modeling activity to understand the contribution of chemical evoluation on different physical mechanisms occurring in the atmosphere and their impacts. In the coming years the group will be involved in improving physical parameterization schemes,

advanced model developments, mesoscale modelling and air quality modeling. Towards this establishment of 500 TFlops High Performance Computing System and 2 PB storage system are planned.

The Computers and Data Management Group's (CDMG) main activities are to maintain the data centre, archival and dissemination of data and maintenance of internet facility. Data from several instruments being operated at NARL are rgularly archived and registered in the data centre. Users can download the data in Binary, ASCII, CSV or NETCDF format. Recently the group has established new fibre optics network at 7 locations in Green Building, which is extended to 24 other locations of our campus. Hybrid mode cable is laid and 15 subnets are created. The network is designed to have 1 G per port connectivity with a 10 G backbone per subnet. The new set up ascertains the separation of internet and intranet with improved performance. The Network is fully operational and centrally managed from the Green-building. In the coming years the augmentation of storage facility, new software for data analysis, advanced methods for data mining are planned.

Apart from the above group activities there are two projects, one for development of different types of lidars and the other for developing space instrumentations. The different lidar technologies such as the Boundary Layer Lidar (BLL), the Dual Polarization LIDAR [DPL] and the Raman Lidar are filed for Indian Patent Rights. The BLL and DPL technologies are transferred to Indian industries and are now made commercially. Recently an infrared lidar with spatial scanning capability is developed for high temporal and spatial resolution studies of the boundary layer evolution. The instrument development group is involved in developing methodologies for reducing the acoustic noise from the Radio Accoustic Sounding System as well as in developing a tethered balloon platform for hoisting various scientific experiments within and above the boundary layer.

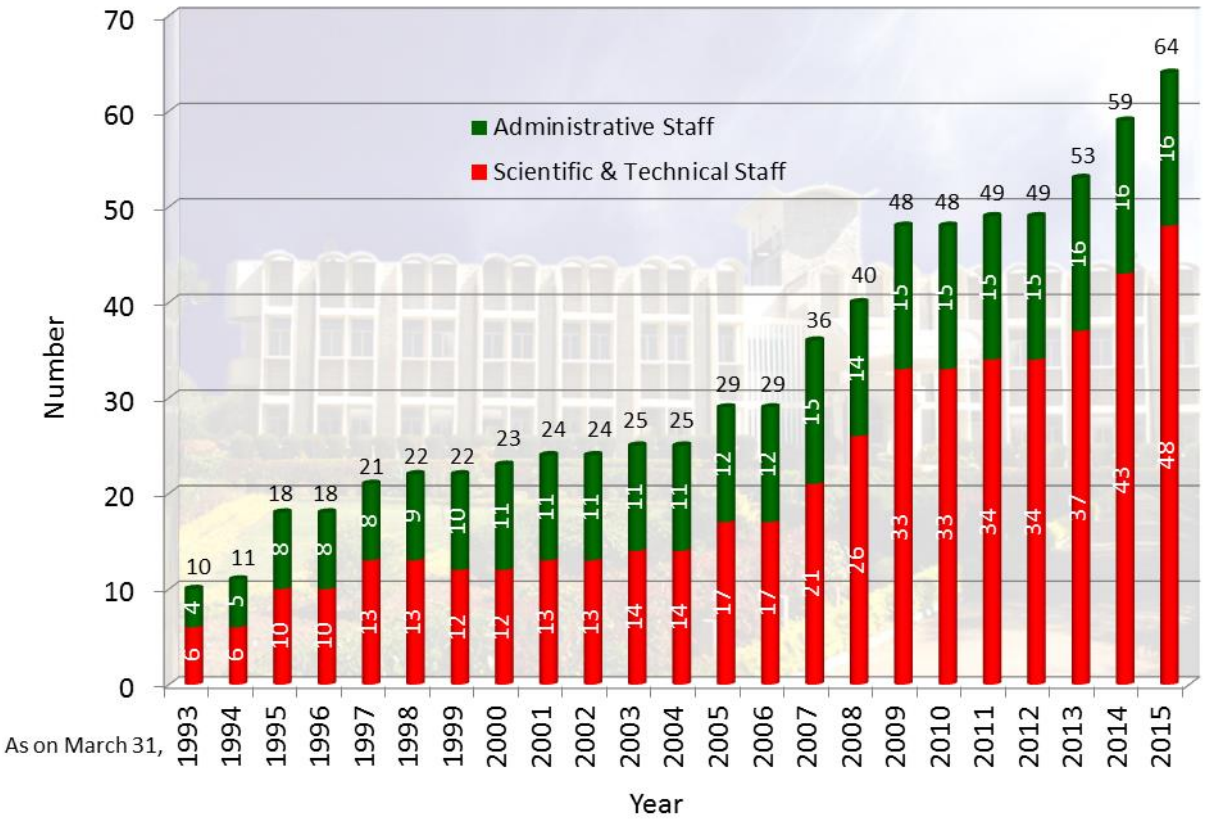
NARL regularly publishes high quality research papers in high impact journals. So far a total number of 483 research papers in peer reviewed journals were published which have a total citations of more than 4306. So far NARL has produced 49 Ph.Ds and also provides guidance to engineering and science students for their B.Tech, M.Sc., M.Tech projects. NARL also conducts workshops/Confenerences and seminars. Till now 47 such events have been arranged. NARL provides necessary facilities to atmospheric science community both national and international for conducting special experiments at NARL as well disseminates data collected under common mode observations. More than 900 GB of data have been disseminated for scientific user groups outside NARL.

October 2015

A. Jayaraman
Director

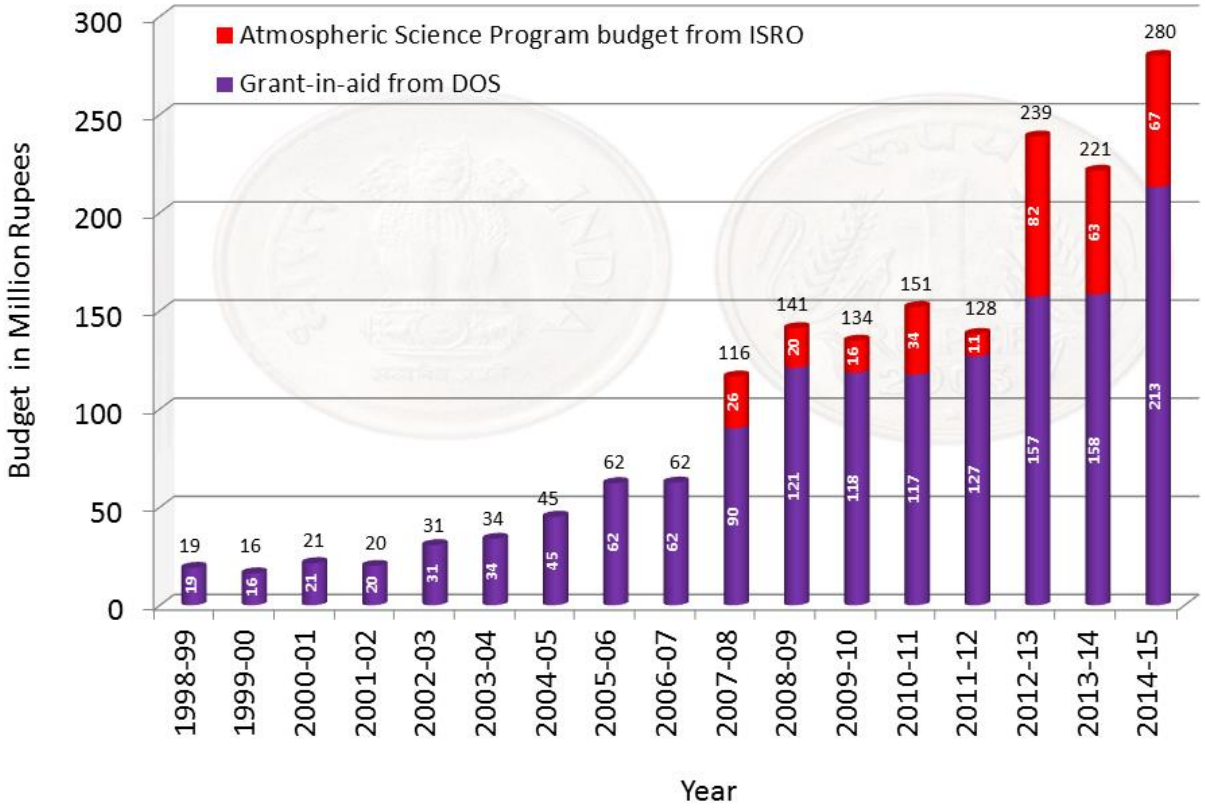
2. Staff (Scientific&Technical / Administrative) profile

During 1993-2015, manpower (Scientific/Technical/Administrative) in NARL has been augmented as shown in the graph below. Presently (as on March 31, 2015) the total staff is strength is 64.

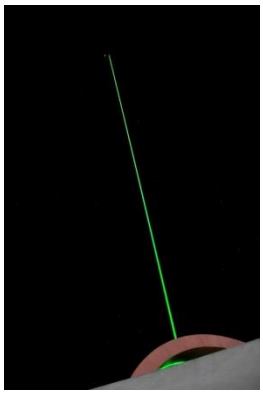


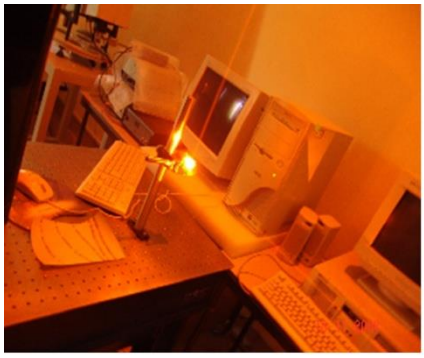
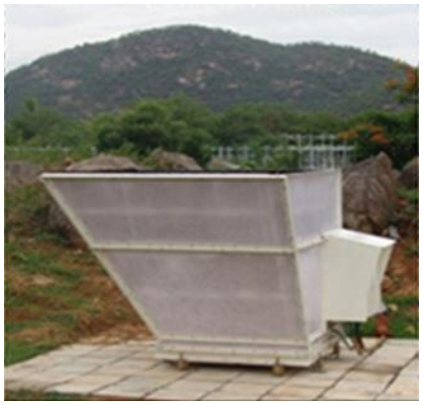
3. Budget profile

The annual budget has been growing from a modest amount of about 20 million Rupees per year in early 2000's to 280 million Rupees for the current financial year. Apart from the Grant-in-aid from the Department of Space (DOS), NARL also receives fund from the Atmospheric Space Science Program of ISRO for specific project since 2007.



4. Research Facilities

MST Radar (1993) 	A high power 53 MHz Mesosphere-Stratosphere-Troposphere (MST) Radar was developed indigenously and operationalised in 1993 as a national facility for atmospheric research. This radar is the second most powerful radar in the world after the 50 MHz Jicamarca radar, located in Lima, Peru. Indian MST radar transmits a peak power of 2.5 MW generated by 32 vacuum tube transmitters and has a 1024-element Yagi-Uda antenna array with an aperture of ~1.7×10^4 m^2 . The radar was designed to study winds, waves and turbulence in the troposphere, stratosphere and mesosphere, and plasma irregularities and electrodynamics in the ionosphere.
Disdrometer (1997) 	A Joss-Waldvogeldisdrometer is used to measures rain drop size distributions continuously and automatically. This instrument transforms the vertical momentum of an impacting raindrop into an electric pulse whose amplitude is a function of the drop diameter. A conventional pulse height analysis yields the size distribution of raindrops. The drop diameters that it can measure are in the range of 0.3 millimeter to 5 millimeter with an accuracy of ±5%.
Rayleigh/Mie Lidar (1998)  	A pulsed monostaticlidar system was established at NARL in collaboration with Communication Research Laboratory, Japan, for the study of atmospheric aerosols and thermal structure of stratosphere and mesosphere. The lidar uses a 532 nm, 600 mJ Nd:YAG laser with a pulse width of 7 ns and 50 Hz PRF. The receiver system employs two channels - Rayleigh channel to cover middle and upper atmosphere altitudes and Mie channel to cover troposphere and lower stratospheric altitudes. The Rayleigh channel uses 750mm telescope in Newtonian configuration. Another 350-mm-diameter Schmidt-Cassegrain-type telescope with a FOV of 1 mrad is used for Mie channel. A PMT with a narrow band interference filter (1.13nm) centered at 532 nm is used after the polarization beam splitter which separates the beam into Cross and Co polarized components. For both Rayleigh and Mie channels, an MCS-Plus (EG&G ORTEC) multi channel photon counter is used for recording the photon counting signals as a function of time (altitude). The dwell

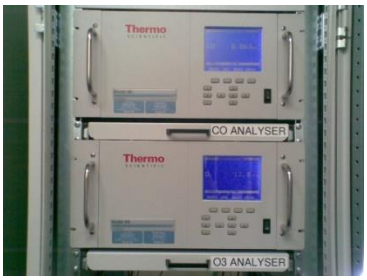
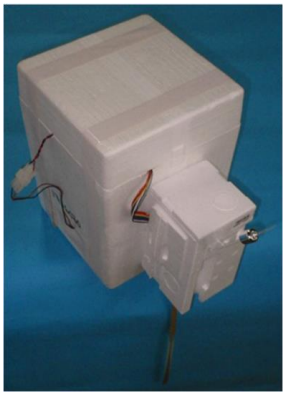
	time of the counting system is 2 µs, which corresponds to an altitude resolution of 300 m. The backscattered returns summed for 250 seconds and are stored in a computer hard disk for off-line analysis.
Sodium Lidar (2005) 	A broadband Na lidar system at Gadanki was setup as augmentation to Rayleigh lidar in a mono-static configuration with the power-aperture product of 0.35Wm^2. The transmitter consists of a tunable pulsed dye laser pumped by a frequency-doubled Nd: YAG laser. The pulsed dye laser is tuned to the D2 resonant absorption line of Na at a wavelength near 589 nm. The dye laser is pumped with 200 mJ at 532 nm to obtain output pulse energy of 25 mJ at 589 nm using Rhodamine 6G as the laser medium. The receiving system uses a 750-mm Newtonian telescope with field optics and an interference filter.
GPS Radiosonde (2006) 	NARL launches GPS radiosonde (RD-11G, Meisei make) daily at 12 UTC since April 2006 for Pressure, Temperature, Relative humidity, Wind Speed and Wind Direction measurements up to the balloon burst altitude, typically 30-35 km. The reported accuracy of temperature, relative humidity and winds are 0.5 K, 7% and 0.5 m/s, respectively.
Doppler Sodar (2007) 	To understand the lowest region of the atmospheric boundary layer (ABL), which is not covered by MST radar and LAWP, a multi-frequency (1600–2500 Hz) phased-array Doppler SODAR system was developed in technical collaboration with the Society for Applied Microwave Electronics Engineering and Research (SAMEER). It was built using piezoceramic tweeters (8x 8 array of antenna elements), which are capable of generating 100-W acoustic power. In favourable atmospheric conditions, the SODAR gives wind profiles from 25 m up to 1 km. The pulse width and inter-pulse period are programmable for getting a range resolution of 10–200 m for an altitude coverage of 1500 m.

MST Radar-RASS (2007) 	By adding an acoustic attachment to the MST Radar remote profiling of atmospheric temperature in the troposphere and lower stratosphere is possible on a continuous basis. Profiles of temperature reaching an altitude of 15 km with a time resolution of 5 minutes is successfully tested. For acoustic system signal is generated at frequency 90–130 Hz with acoustic power of 140 dBA and it uses Hyperbolic horn antenna.
LAMP (2007) 	Lidar for Atmospheric Measurement and Probing [LAMP] is a single channel mono-static coaxial LIDAR which works on the principle of elastic scattering of radiation. It mainly consists of a diode-pumped Nd:YAG Laser, which emits laser pulses of pulse energy between 1-25 µJ at a wavelength of 532 nm with a pulse-repetition rate of 2.5 kHz, a 150 mm diameter Cassegrain type telescope for collecting the back-scattered photons from the atmospheric scatterers (like air molecules, aerosols and cloud particles) and a photon-counting system (photomultiplier tube, discriminator and a PC based multi-channel scalar). This system is developed in NARL and patented under ISRO.
Sky Radiometer (2008) 	PredeSkyradiometer (Prede Co. Ltd., Tokyo, Japan) is an instrument to measure direct solar radiation and directional sky radiation with respect to sun position. The instrument has automatic sun-tracker and filter wheel with seven filters namely 315 nm, 400 nm, 500 nm, 675 nm, 870 nm, 940 nm and 1020 nm. The instrument is used to get aerosol optical depth at five wavelengths, columnar aerosol size distribution, columnar single scattering albedo, columnar average refractive index of aerosols and columnar water vapour.
Aethalometer (2008) 	Aethalometer (Model AE-31E; Magee Scientific Company) is a self-contained, automatic instrument which measures mass concentration of 'Black' or 'Elemental' carbon particles ('BC' or 'EC') in ambient air. It collects the air sample as a spot on a roll of quartz fibre filter tape and simultaneously measures the optical attenuation at seven different wavelengths ranging from 370 nm to 950 nm which is related to concentration of BC on the tape. It gives continuous reading at an interval selectable by user which is typically 5 minutes.

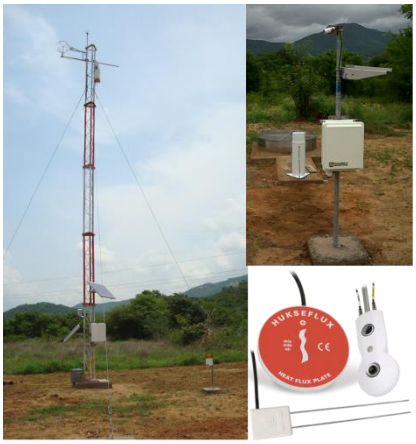
Airglow Photometer (2009) 	A simple multi-wavelength airglow photometer which has F/2 optics has been developed to measure mesospheric OH (at 840 and 846 nm rotational lines from ~85 km) and O2 (at 866 and 868 nm rotational lines from ~94 km) emissions together with thermospheric O(1D) (~220 km, 630 nm) emission intensities with the help of seven temperature controlled interference filters having FWHM ~0.45 nm. The temperatures are derived at OH and O2 emissions using the ratio and slope methods respectively. The MLTP uses H7421-50 photon counting module as detector. The data is saved on a computer hard disk in ASCII format for further analysis. Usually it is being operated on all the clear sky nights.
50 m Meteorological Tower (2009) 	The 50-m instrumented tower is being operated at NARL since 2009. It hosts both fast sensors (Sonic anemometer – RM Young (81000) and IR hygrometer – Li-COR) at two levels (4 m and 8 m) and slow sensors for meteorological parameters (temperature, relative humidity, wind speed and direction) at 6 levels (2, 4, 8, 16, 32 and 50 m). The pressure and incoming shortwave and longwave radiation are measured at 1.2 m altitude. The radiation sensors, soil temperature and moisture profile probes and a tipping bucket rain gauge were installed 20 m away from the tower towards south to minimize shadow effects. The sensible and latent heat fluxes are estimated using eddy covariance technique. The fluxes along with radiation and sub-surface measurements provide an opportunity to study the energy balance in a variety of atmospheric conditions.
Nephelometer (2009) 	Scattering coefficient is measured using integrating nephelometer (Model: TSI 3563). Nephelometer gives hemispherical total (integrated between 7 to 170 degree) and back (integrated between 90 to 170 degree) scattering coefficient at three wavelengths 450 nm, 550 nm and 700 nm. Relevant calibration constants are used to convert the measured photon counts into corresponding scattering coefficient. Once in every hour sampling air is filtered for aerosol to obtain scattering due to clear air, which is subtracted from sample air to get scattering due to aerosol. Calibration constants are determined by using CO_2 gas at about six monthly interval. The instrument is continuously operated and the data are saved as five minutes averages.

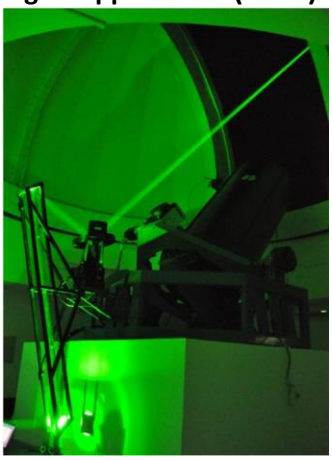
Aerodynamic Particle Sizer (2009) 	Aerodynamic Particle Sizer (Model : 3321, TSIInc, USA) is used to measure the surface aerosol number size distribution in 52 bins for aerodynamic diameter ranging from 0.5 µm to 19.8 µm. It uses the time of flight technique for estimating the aerodynamic particle diameter in the real time. The ambient air is drawn through an inlet port at a flow rate of 5 litre per minute using internal pumps. The instrument is operated with time resolution of 5 minutes since October 2008.
Dual Freq. GPS Receiver (2009)/ GNSS Receiver Network (2010) 	To continuously monitor the ionospheric TEC and Scintillations, a dual frequency (L1=1575.42 MHz and L2=1227.6MHz) GPS receiver (Novatel GSV4004B) has been operational at Gadanki. The receiver provides true amplitude, single frequency (on L1) carrier phase measurements and TEC measurements from up to 11 GPS satellites in view from 22 hardware digital channels. It also tracks SBAS (GAGAN) satellite, providing L1 code pseudo-range measurements and Scintillation data. At present a total of eight GPS/GNSS receivers at different locations have been installed under collaboration.
Data Center (2009) 	A state-of-the-art data center has been established as per Tier–II International Data Center Standards during 2009. This data center acts as the central repository of all the data from the co-located facilities of NARL. It is configured in D2D2T architecture with Information Lifecycle Management (ILM), ensuring secured and spontaneous access to the data. The data dissemination policies are kept minimal while ensuring maximum and proper usage of data by user with extreme ease.
Lower Atmospheric Wind Profilers (LAWP) (2010) 	NARL has developed two L-band radars for Lower Atmosphere Wind Profiling (LAWP) and precipitation studies. These radars operate at 1280 MHz and employ the Doppler beam-swinging (DBS) technique for measuring the wind vector. The radar has been configured and demonstrated with an active array, first of its kind in its class of atmospheric radars. A simplified active array configuration is adopted to make the radar simple, compact, rugged and low cost. In this configuration, a modified version of the two-dimensional Butler multi-beam forming matrix feeds the solid-state transmit-receive modules energizing the individual microstrip patch antenna elements

	of a planar array. The received atmospheric echoes are processed with a state-of-the-art direct IF digital receiver/processor. Two systems have been developed; one transportable radar with 1.4-m size 8x8 array and one fixed radar with 2.8-m size 16x16 array.
LAWP-RASS (2010) 	With the aim of extending the temperature profiling capability at NARL downwards below 1.5 km RASS technique was applied to the LAWP. For this purpose, acoustic attachments were constructed and installed. Commercial off-the-shelf components were used for the development of acoustic transmitter.
Pyranometer and Pyrheliometer (2010) 	Kipp and Zonenpyranometer with automatic sun-tracker and four sensors is used to measure broadband surface reaching solar radiation. Two of these sensors are used to get diffuse flux whereas one for total (direct+diffuse) and one for direct solar radiation.
Total Sky Imager (2010) 	Total sky imager is an instrument which records true color RBG images of hemispherical sky. The images are recorded at every five minutes during daylight hours. An image processing software estimates the cloud fraction from this image.
Dual Polarisation Lidar (2010) 	The DPL system utilizes a single flashlamp pumped 532 nm, 30 mJ, 20 Hz PRT Nd:YAG laser as transmitter and uses a 150 mm Schmidt–Cassegrain telescope with PMT based signal detection as the receiver. The best vertical resolution of this system is 7.5 m. The data acquisition system of DPL employs both analog and photon counting electronics, which makes the system capable of operating both during day and night without pause. The DPL provides aerosol /cloud backscatter at and also provide depolarization ratio covering the lower atmosphere.

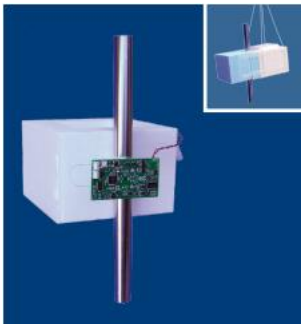
Trace Gas Analysers (2010) 	Four trace-gases namely ozone, oxides of nitrogen, sulfur dioxide and carbon monoxide are monitored using continuous on-line trace-gas analyzers (Model: 41i, 42i, 48i, 49i, Thermo Scientific Co., USA). The concentrations are monitored continuously and recorded as five minute averages since February 2010.
Ozonesonde (2011) 	NARL launches Electro -chemical Concentration Cell (ECC) ozonesonde (RS-06E, Meisei make) every fortnight since 2011 around local noon. This ozonesonde measures ozone by electro chemical oxidation of potassium iodine by ozone in aqueous solution. The ozonesonde is connected to the Meisei GPS Radiosonde through interface connector in order to measure atmospheric pressure (P), temperature (T), relative humidity (RH) and wind speed and direction along with vertical ozone distribution The accuracy of the ECCOzonesonde is ~5-10%.
2D Video Disdrometer (2011) 	To augment the instruments that provide microphysical information of rainfall at NARL and to derive relations that are being used in satellite and radar rainfall retrievals, NARL is operating a highly sophisticated 2D Video disdrometer (2DVD), supplied by Joanneum Research, Austria. The 2DVD provides accurate measurement of raindrop size distribution (DSD) and information on raindrop shape.
Micro Rain Radar (2011) 	The Micro Rain Radar retrieves quantitative rain rates, drop size distributions, radar reflectivity, fall velocity of hydro meteors and other rain parameters simultaneously up to several kilometers above the radar. It operates at a frequency of 24 GHz with a modulation of 0.5 – 15 MHz.

Microwave Radiometer (2011) 	Microwave radiometer (MWR) monitors the water vapour absorption line at 22 GHz to determine the water vapour profile. MWR monitors radiated power in a molecular oxygen absorption band around 60 GHz to determine temperature profiles and radiative power at selected frequencies of 22 to 59 GHz together to determine the liquid water profile. Cloud base height is estimated from zenith-infrared observations and retrieved temperature profiles.
Multifilter Shadow-band Radiometer (2011) 	Multi filter shadow band radiometer (MFR-7) is a seven channel (6-narrow bands; 1-broad band) radiometer intended to measure diffuse, total and direct normal components of radiation. A thin membrane acts as an aperture for the sensor assembly consisting of photo-diodes with narrow band interference filters. The narrow bands are selected in such a way that the columnar abundance of water vapour (940nm), aerosol (500nm) and ozone (415nm) is measured along with broad band radiation.
Rain Gauge Network (2011) 	A meso-rain gauge network covering an area of 50 km × 50 km, was established during 2011-12 to generate a highly accurate rainfall product that can serve as a reference in the evaluation of meso-scale model outputs and satellite precipitation estimates. The network consists of 36 rain gauges arranged in a near square grid of spacing ~10 km and is centered on Gadanki. The rain gauges are of tipping bucket type with 0.2 mm bucket and provide rain information with one minute temporal resolution. There is a provision to store the data at the site and also to transfer the data to a server located at NARL through GPRS technology.

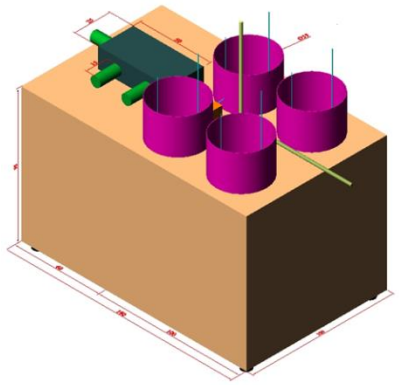
High Performance Computing System (2011) 	NARL has established high performance computing facility for weather and climate modelling and forecasting research. The total peak computing power of the HPC is 28 TF, out of which 10 TF is computational clusters and 18 TF are in terms of SMPs and Multi-Integrated Core (Intel MIC) coprocessor servers. The cluster system consists of 34 blade servers with each server having 12 cores and 72 GB of RAM. These systems have total of 430 TB online scalable storage and 870 TB of LTO5 tape backup facility. The whole system is interconnected with high speed infinibandQDR network for faster data transfer. The HPC system is currently being used for real time weather forecast over Indian peninsula especially over SHAR and Gandanki. This facility is also used by scientists and research students of NARL to run their computationally intensive simulation for their research. The simulation of 251 years of climate (1850-2100) has been successfully carried out on this system using Community Earth System Model version 1.2.1z (CESM) with coupled ocean-atmosphere-land-ice-land surface schemes.
Eddy Covariance Flux Tower (2011) 	NARL has 10 meter Eddy Covariance Tower (ECT, Campbell Scientific Inc., USA) for surface flux measurements. ECT is instrumented with sonic anemometer thermometer (CSAT 3, Campbell Scientific Inc., USA), H_2O/CO_2 gasanalyser (LICOR Biosciences, USA) and Fine wire thermocouple (Campbell Scientific Inc., USA) at 10 meters, and dry bulb temperature, relative humidity, barometric pressure and tipping bucket rain gauge measurements at 2 meter level. These observations are available at 1 Hz temporal resolution to calculate sensible and latent heat fluxes, momentum fluxes and friction velocity using the eddy covariance technique. The NET radiometer and IR thermometer are also installed along with this tower to understand surface energy balance and PAN evaporimeter to measure the evaporation from the surface. Survafec parameters (temperature, moisture and heat fluxes) are measured using soil temperature probes, soil water content reflectometers and soil heat flux plates at various depths.

Raman Lidar (2012) 	Raman LIDAR system has been successfully operational at National Atmospheric Research Laboratory (NARL) for remote sensing the atmospheric watervapour and aerosols in the boundary layer. The Raman Lidar (RL) system uses both elastic and molecular Raman scattering and provides continuous height profiles of watervapor and aerosol in the boundary layer during night-time periods.
Airglow Imager (2012) 	The Airglow Imager which provides real time information on the spatial scales and direction of propagation of the dynamical variability at mesospheric altitudes (OH and O(1S) emissions) and thermosphere-ionosphere system (O(1D) emission) is being installed at NARL. The imager uses a circular medium format F/4Mamiya fish eye lens with a focal length of 24mm. It measures OH, O(1S) and O(1D) emissions at peak wavelengths 840, 558 and 630 nm respectively. The detector is a back illuminated e2v CCD47-10 chip (Acton Pixis 1024B) CCD with 1024x1024 square pixels of 13.3 µm size having 100% fill factor and 16 bit depth. The final image captured by the imager is stored on the computer hard disk for further analysis.
Rayleigh Doppler Lidar (2013) 	Rayleigh Doppler Lidar (RDL) has been developed for the measurement of tropospheric and stratospheric mean winds. RDL uses a high energy laser with 30W power @532nm and 50Hz repetition rate to get atmospheric backscatter from molecules and particles. A 750 mm telescope in Newtonian configuration is used to collect the backscattered signal and a Fabry Perot Interferometer is employed as amplitude discriminator to get the radial winds. The system is capable of moving the telescope in 0-360 degree along azimuth and upto 45 degrees off zenith. This system has been demonstrated to measure Zonal and Meridional winds in the 10-50 km altitude range. The winds, derived from this indigenously developed system have compared well with near simultaneous GPS Radio Sonde winds.

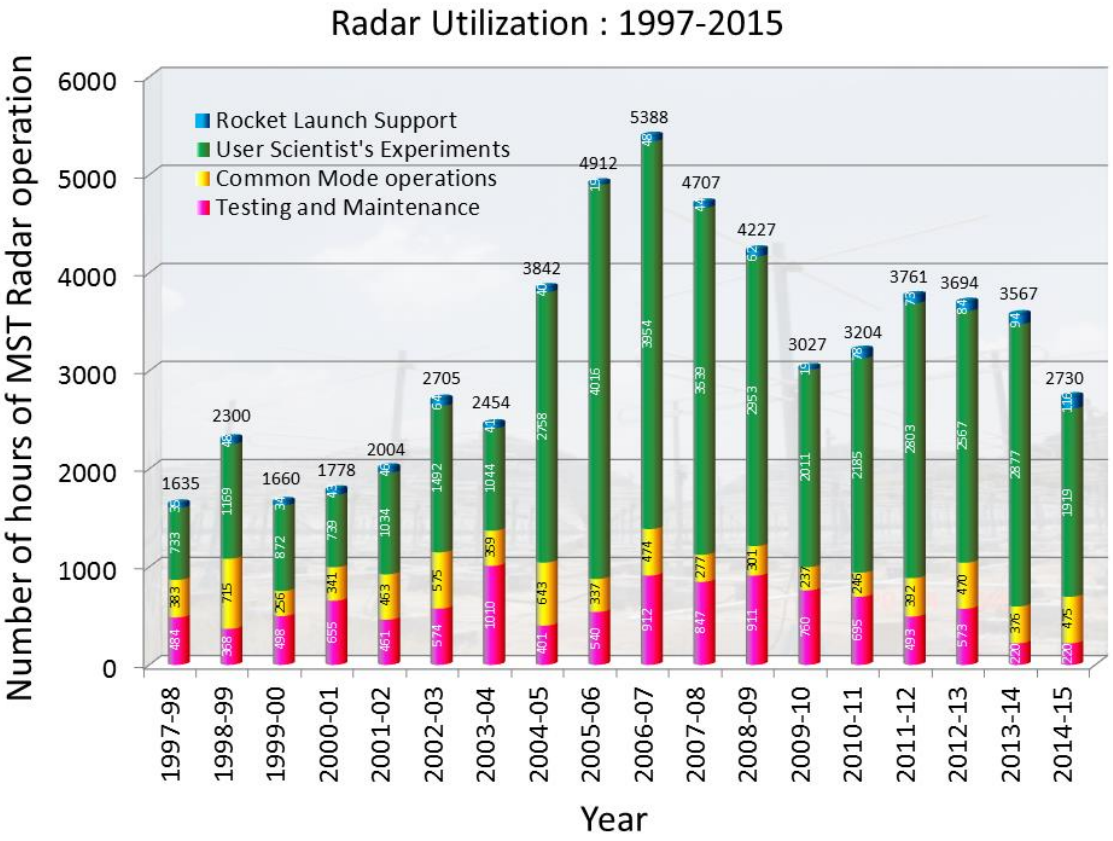
HF Radar (2013) 	A 30-MHz radar has been developed at NARL for studies of the low latitude Ionospheric plasma irregularities. The radar has the beam steering capability to scan upto ±45^{o} in East-West direction. The radar system employs an active phased antenna array and high power solid-state Transmit-Receive (TR) modules. The antenna beam is fixed towards 14^{o} North from Zenith for the detection of the irregularities from the ionospheric E and F regions. The Radar system comprises of 160 two-element Yagi antennas arranged in a 20x8 matrix over an area of 112m x 56m. A total peak power of 150 kW is generated by 20 numbers of 7.5- kW solid-state TR Modules, each feeding a column of 8 antenna elements in North-South direction.
Cloud and Aerosol Lidar (2014) 	This is a single channel elastic backscatter LIDAR technology for profiling the cloud base height during convective periods with high spatial and temporal resolutions. The transmitter uses a 1064 nm, 15 mJ, 20 Hz PRT laser and the receiver uses 150 mm telescope with avalanche photodiode (APD) for signal detection. The receiver employs a 12 bit ADC sampling at 20 MHz rate. The LIDAR can be operated either in zenith or slant angle modes. The slant angle mode operation of LIDAR is suitable for cloud base measurements during convective periods.
Ionosonde (2014) 	A DPS-4D digisonde has been installed for continuous monitoring of the ionosphere. DPS-4D is a sweep frequency HF radar and works in the frequency range of 1-30 MHz. Radio wave is reflected from the ionosphere due to plasma frequency reflection and is also scattered from the ionospheric plasma irregularities. Digisonde observations can be used to get electron density profile and drifts in the ionosphere.

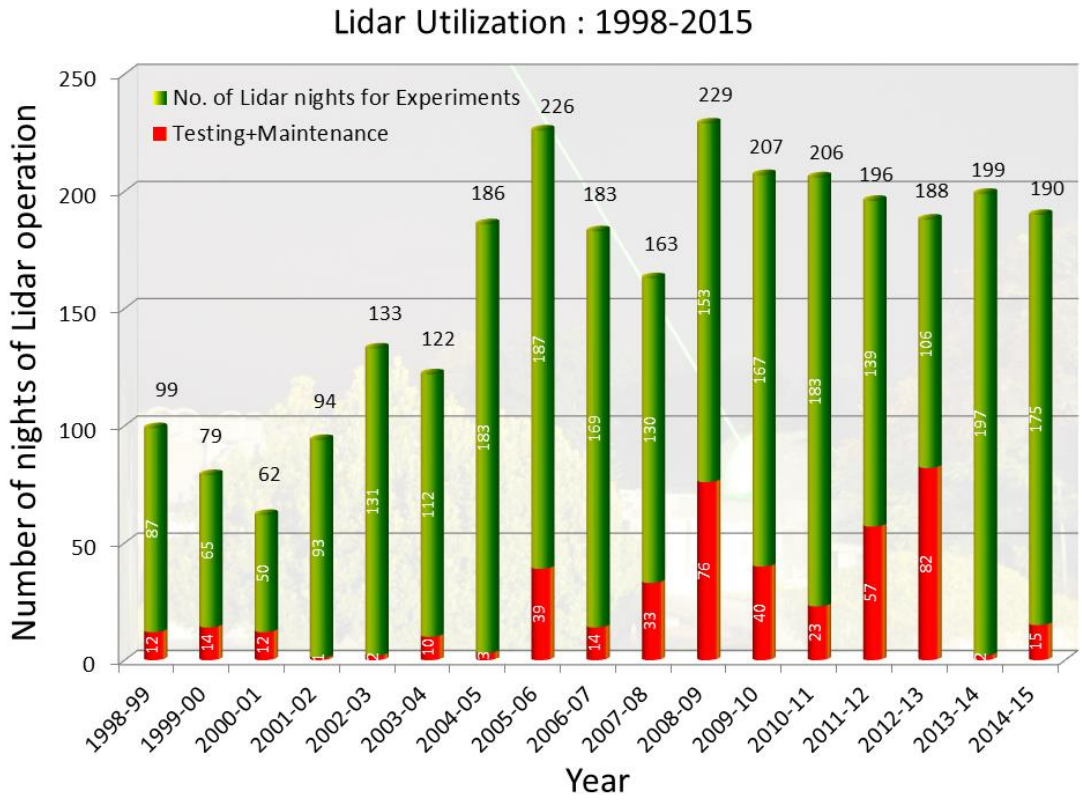
Brewer Spectrometer (2014) 	The Brewer Mk III Spectrophotometer provides high accuracy measurements of UVA, UVB, UVE, total column Ozone and Sulphur Dioxide (SO2). Some aerosol properties (Aerosol Optical Depth) can also be derived from the data. Using Umkehr method, profiles of ozone from surface to 50 km can also be obtained using sun's occultation (typically during sunrise and sunset times). This system is installed in Sep.2014. It operates in the wavelength ranging from 286.5 to 363 nm with wavelength resolution of 0.6 nm, wavelength stability of ±0.01 nm, wavelength precision of 0.006 nm (±0.002 nm) per step. Ozone and SO2 are measured in the wavelengths of 303.2, 306.3, 310.1, 316.8 and 320.1 nm.. Coolum ozone is measured with an accuracy of ±1%.
UV Radiometers (2014) 	Two broad-band UV radiometers (UV-B 280 to 340 nm and UV-A 340 to 400 nm) are included in the suite of measurements carried out from the climate observatory in 2014. Global UV radiations are continuously measured and the data are saved as five minute averages.
A-MLTP (2015) 	The Advanced Mesosphere Lower Thermosphere Photometer monitors mesospheric OH and O2 lines together with thermospheric O (1D) line emissions simultaneously. It is a cluster photometer with a capability to scan the sky within 90 seconds. This enables the investigation of very fine structure evolution noted in mesosphere-thermosphere-ionosphere system.
Cryogenic Frost Point Hygrometer (2015) 	NARL also launches Cryogenic Frost Point Hygrometer (CFH), obtained from Droplet Measurements Technologies, on periodic basis for getting accurate measurements of water vapour. This CFH accurately measures water vapor from the earth's surface to the mid-stratosphere (25-28 km). The instrument has significantly greater sensitivity to water vapor than standard radiosondes, as it can measure amounts at the parts-per-million level. It measures water vapor with the uncertainty of 4% in tropical lower troposphere and <10% in middle stratosphere.

INSTRUMENTS UNDER DEVELOPMENT/PROCUREMENT	
Active Array MST Radar 	An upgradation project has been taken up to replace the vacuum tube-based transmitters and semi-active antenna array with 1024 solid-state 1-kW transmit-receive (TR) modules each feeding one Yagi antenna making the radar system fully active with antenna beam pointing flexibility covering 360^{o} azimuth, which does not exist in the present system. Most importantly, this will allow conducting multi-receiver experiments for Spaced Antenna and Radar Interferometry/Imaging analysis of atmospheric echoes for in-beam imaging of refractive index field and winds.
Tethered Balloon Observation Platform 	A tethered balloon observation platform (TBOP) is being developed to obtain the height profiles of aerosol and trace gas concentrations, outgoing solar radiation, turbulence intensities etc., up to 500 m. It consists of an instrument enclosure equipped with 3.9 kWH Li-Ion battery, ethernet power switching relay bank, GPS positioning receiver,radar altimeter, WiFi access points, Linear Low Density Poly Ethylene (LLDPE) natural (pear) shaped balloon, Vectran tether, 1Ton Electrical winch etc. Atmospheric measuring instgruments up to 20 kg can be hoisted with this system.
Gas Chromatograph & Green House Gas Analyser 	A gas chromatography based Volatile Organic Compound (VOC) analyser will be added to the ICON observatory in near future. This nstrument is capable of measuring 54 VOCs listed by US EPA as ozone precursor molecules. A Green HouseGas (GHG) analyser capable of measuring Methane (CH4), Carbon Dioxide (CO2), Carbon Monoxide (CO) and Water Vapour (H2O) will also be added to ICON observatory in near Future (in beginning of 2016).
Differential Absorption Lidar	To investigate the role of UTLS ozone on Stratosphere-Troposphere Exchange (STE) processes, Differential Lidar project was take up for study of ozone concentrations at those levels. The system operates at ON and OFF wavelengths of 289 and 299 nm in troposphere region and 355 and 308nm for stratospheric regions. From the differential absorption at these two wavelengths ozone

	concentartion levels are calculated. The system uses fourth harmonic of NdYAG laser for pumping a Raman cell filled with D2 and H2 gases from which Raman shifted wavelengths are generated. The receiver contains a 50 cm telescope and the signal so collected is acquired through analog and photon counting methods.
X-band Radar 	State-of-the-art X-band polarimetric radar is being developed in collaboration with ISTRAC, ISRO, Bangalore for understanding microphysical properties of precipitation and evaluating satellite-based precipitation estimates. Besides quantifying the precipitation rates accurately, the X-band polarimetric radar provides information on microphysical information of size and phase of hydrometeors over a large area (~60 km radius around Gadanki). The scanning capability of X-band radar augments the vertically pointing systems at NARL and opens up a new area of research on precipitation.

5. Radar and Lidar Utilization





6. Infrastructure Developments

Construction and Maintenance Division

Group Members

Head : Mr. K. Vasudevan , DEE, (B.Tech), Scientist / Engineer–SF

Scientific / Technical staff

Mr. P. Ravi Prasad, B. Tech, (M. Tech), Scientist / Engineer–SD (Civil)

Mr. U. Babu, DCE, Technician–F (Civil)

Photograph: Office building of Construction and Maintenance Division, NARL

Objectives

Construction of all ground based structures and associated utilities to cater to the research needs of NARL.

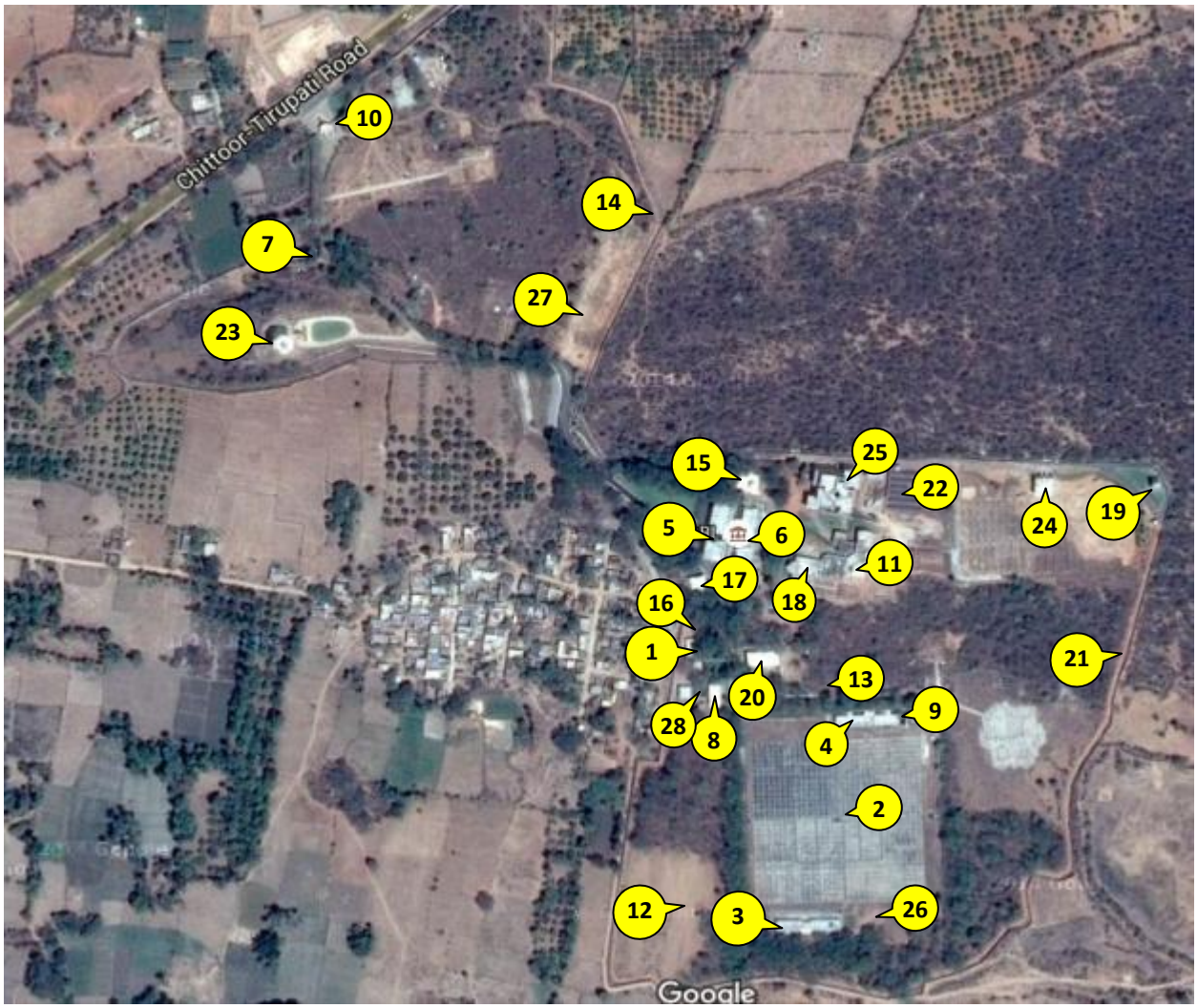
To execute all maintenance and modification works in respect of civil, electrical and AC systems at NARL.

To ensure reliable power and water supply to NARL projects and facilities.

To maintain clean and green environment in the campus.

Overview on establishment of NMRF/NARL

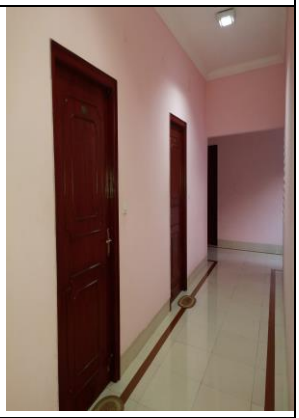
To establish MST Radar facility Gadanki site was chosen based on the various considerations like availability of a flat land surrounded by the hills, proximity to the university, ISRO Center, latitude, radio noise level and interference, frequency clearance etc. Project management board towards realization of the MST Radar was constituted by Prof. U.R.Rao, Chairman, ISRO. Civil Engineering Division of the SHAR Centre had taken up the infrastructure development work initially in 1989. During the later years following facilities were developed as marked in the attached map.



1. **CED site office (1989)** (Augmented for CMD office in 2007)	15. Boundary Layer LIDAR building (2007) extended for Raman Lidar in 2010
2. MST radar in 4 acres of land (1990) Flooring in 2000	16. 2 wheeler parking (2010)
3. South HUT (16 transmitters are housed) (1990)	17. 4 wheeler parking (2010)
4. North HUT (16 transmitters are housed) (1990)	18. Wind profiler building (2009)
5. Main building (1990)	19. ICON building (2009)
6. Service building (1990)	20. Central stores and workshop (2009)
7. Security gate (1990)	21. Slab model compound wall Phase – II with patrolling pathway (2010)
8. LIDAR building (1998) extended for Doppler LIDAR, 2011	22. 50 KWp Solar power generating system(2011)
9. CRI building & 133 antennas (2005)	23. X band Radar Building (2012)
10. Main gate complex (2005)	24. HF radar building & antenna array (2013)
11. Conference hall & 4 nos. guest rooms (2006)	25. Green building for augmentation of lab & office (2015)
12. Ionosonde (2006) Digisonde (2014)	26. Shed for cylinder storage and platform for tethered balloon launch (2015)
13. SODAR facility (2006)	27. Students hostel (Work in progress)
14. Compound wall Phase – I (2006)	28. Scanning CBL Lidar (Work in progress)

Major Infrastructural Accomplishments

1996	1997
***Housing**: Director's residence, 2 Nos. 'D' type, 4 Nos. 'C' type, 3 Nos. 'B' type, 2 Nos. 'A' type along with a pump house.*	***Guest house**: Consisting of 5 Nos. of two bedded guest rooms, 25 seating capacity meeting room, small kitchen with dining and reception.*
1998	**1999**
***LIDAR building**: To house Rayleigh/ Mie Lidar transmitters and receivers.*	***Dormitory**: 4 Nos. of two bedded rooms for students.*
1999	**2000**
***Staff quarters**: One 'D' type was constructed.*	***Staff quarters**: 2 Nos. of 'C' type and 2 Nos. of 'B' type were constructed.*

2004	2005	
***MST RADAR flooring**: RCC precast cement slab / RCC flooring was done for the antenna array area of 16900 m^2.*	***CRI project**: construction of building to house transmitters and receivers in two floors, levelling of site and construction of 304 antenna pedestals.*	
2005	**2005**	**2006**
		
***Entrance gate complex**: Consisting of in and out roads, compound wall with name boards, ornamental security kiosk, water fountain etc.*	***Additional staff quarters:** 2 Nos. D-type & 2 Nos. E-type were constructed.*	*Visiting Scientist Hostel at NARL campus, Tirupati.*
2006		
***Conference hall & guest rooms**: To accommodate 100 members, conference cum seminar hall was built with 4 Nos. of guest rooms.*		

2007	2007
***Boundary layer LIDAR**: To house BLL Lidar and Lidar development activities.*	***Reception:** Construction of reception and foyer in the main building.*
2008	**2009**
***Committee room:** Old Guest rooms were modified as committee room, Director's chamber and visiting scientist's room.*	***Wind profiling facility**: To house 16 x 16 wind profiler, GPS balloon launch facility and laboratory space for Sci./ Engrs.*
2009	**2009**
***ICON**: Construction of the Climate observatory to house instruments for measuring essential Climate variables.*	***Central stores**: Construction of Centralized stores and workshop.*

2010	2010
***Compound wall**: Existing Chain-link and barbed wire fencing was replaced with RCC slab model compound wall and patrolling pathway for a length of 3.2 km.*	***Vehicles parking facility**: Parking facility for four wheelersand two wheelers were constructed.*
2010	**2011**
***Augmentation to BLL**: Existing BLL building was augmented to house Raman Lidar, Dual polarization Lidar and LAMP.*	***Doppler LIDAR facility**: To house Rayleigh Doppler Lidarlab space has been created with motorized mobile dome with 360 degrees rotation.*
2011	**2011**
***50 KW peak solar power plant**: 50 KWp Solar power generating system was established to meet the Green building requirements.*	*Renovation of North and South Transmitter HUTs.*

2011	2012
***Additional Staff Quarters**: 2 Nos. D-type & 2 Nos. E-type were constructed at Tirupati.*	***CI room:** Face lift to control and Instrumentation room.*
2012	**2012**
***X– Band RADAR Building:** To accommodate X-band radar along with conference hall, guest rooms. .*	***Rain water harvesting**: Revetment works were carried out at many places to prevent soil erosion and for rain water harvesting.*
2012	**2013**
***Recreation facility**: Recreation facility has been created at NARL and NARL housing colony.*	***30 MHz Coherent backscatter RADAR**: Levelling of site, construction of 160 Nos. of pedestals and building to house Tx and Rx along with Ionospheric instruments.*

2014	2014
***Ionosonde**: Civil works related to installation of Digisonde along with its receivers, walk ways, platforms for data analysis room.*	***Cable Trench:**About 1 km built in trench was constructed to accommodate electrical, RF, optical and other data cables at all over the NARL.*
2015	**2015**
***Battery operated golf cart**: 5Nos. of battery vehicles including one truck were procured to minimize the pollution in the campus.*	***Tethered balloon launch facility**: An area of 1920 $m^2$was developed towards motorized balloon launch activities along with shed for hydrogen storage.*
2015	

Augmentation of laboratory and office areas (GREEN BUILDING)*: To augment lab and office area such as library, board room, HPC lab, Data storage lab, JRF room, DIAL lab and to accommodate WCRG, ARTG, CDMG groups a new building has been constructed with green concepts.*

Way Forward

- Increasingthe present level of satisfaction ratio of staff quarters from 40 % to 75%.
- Acquisition of land for expansion of developmental activities of NARL.
- Solving water problem in NARL housing complex, Tirupati.

Work plan

- Construction of Students Hostel Consists of 18 Nos. of hostel rooms, Recreation & Dining block and 6 Nos. of suite rooms for visiting scientists.
- Construction of three storied building to house the scanning CBL LIDAR.
- Civil and Electrical related works towards realization of active array MST RADAR project.
- Over Head Tank (OHT) of 100 m^3 capacity with 20 m staging and Ground Level Reservoir of 120 m^3capacity at NARL Campus.
- Renovation and Augmentation ofelectrical Sub Station.
- Construction of Administrative building and new Residential Complex at Gadanki campus.

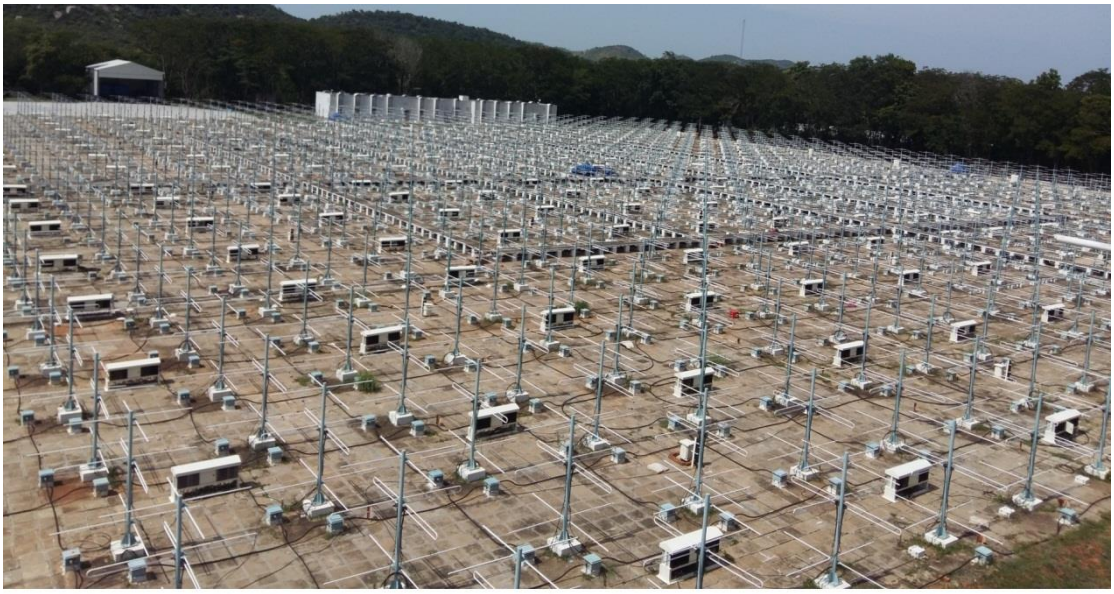
7. Scientific and Technical Accomplishments and Way Forward

7.1 Radar Applications and Development Group
7.2 Ionospheric and Space Physics Group
7.3 Atmospheric Structure and Dynamics Group
7.4 Clouds and Convective System Group
7.5 Aerosols Radiation and Trace Gases Group
7.6 Weather and Climate Research Group
7.7 Computers and Data Management Group

Projects

7.8 LIDAR
7.9 Advanced Space-borne Instrument Development

7.1 Radar Applications & Development Group (RADG)



Group Members

Head: Prof. A.Jayaraman, M.Sc.,Ph.D., OS

Scientific/Technical Staff

Mr. T Rajendra Prasad, M.Tech.,(Ph.D), Scientist/Engineer-SE
Mr. M DurgaRao, M.Tech.,(Ph.D), Scientist/Engineer-SE
Ms. P Parvathi, ME, Scientist/Engineer-SE
Ms. P Yasodha, M.Tech.,Scientist/Engineer-SD
Mr. P Kamaraj, M.Tech.,(Ph.D), Scientist/Engineer-SD
Mr. K Jayaraj, B.Tech.,(M.Tech), Scientist/Engineer-SC
Mr. J Kamal Kumar, B.Tech., Scientist/Engineer-SC
Mr. K M V Prasad, B.Tech., Scientist/Engineer-SC
Ms. A Thriveni,M.Tech., Sr. Tech Asst
Mr. J Raghavendra,B.Tech.,(M.Tech), Sr. Tech Asst
Mr. D MadanaGopal, ITI.,(DECE), Tradesman-F

Photograph: Active Phased Array MST Radar Antenna Array field with solid state TR modules

Objectives

Indigenous development of wide varieties of radars for atmospheric studies from Boundary Layer (BL) to Ionosphere.

Development of state-of-the-art technologies like solid state Transmit/Receive modules, Direct Digital Synthesizer (DDS) based RF exciter, multi-channel direct digital receivers and antenna systems for radar applications.

Development of data processing algorithms and data products.

Providing wind profiles to SDSC, Sriharikota to support the ISRO satellite launch missions.

Regular operation and maintenance of the existing radars.

Major Developmental Accomplishments

- ✓ In-house development of 1 kW Solid-state transmit-receive (TR) module at 53 MHz, and its scientific validation by energizing 12-element antenna array.
- ✓ Development of state-of-the-art Lower Atmospheric Wind Profiling radar (LAWP) operating at 1280-MHz for lower atmosphere research.
- ✓ Development of 53-MHz pilot active array radar system as a pre-cursor to up-gradation of the MST Radar into a fully active array system.
- ✓ Indigenous development of 30-MHz coherent Back scatter Radar using state-of-the-art technologies for high resolution spatio-temporal mapping of ionospheric irregularities, meteor and space weather research.
- ✓ Development of multi-channel digital receiver system to facilitate experiments like spaced antenna/Interferometry and meteor studies.
- ✓ In-house development of radar data processing software for deriving winds and associated products.

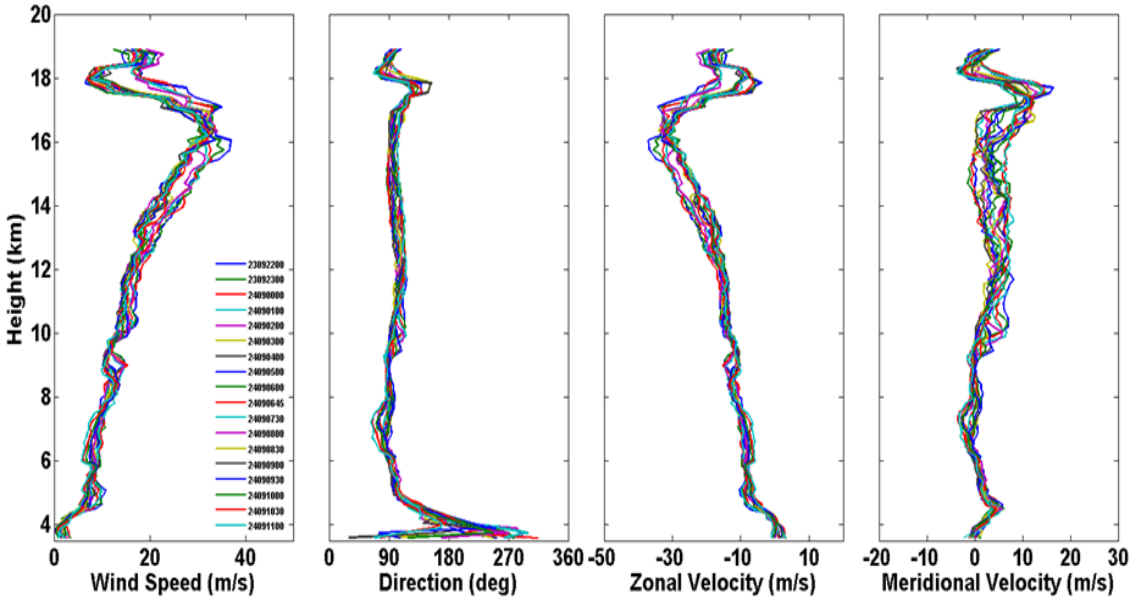


Figure 1. *The variations in wind profiles during one of the recent launch campaign (PSLV –C30). NARL participated in about 45 rocket launch campaigns from SDSC-SHAR providing atmospheric wind profiles (up to 20km height) measured by MST Radar, including Chandrayaan-1, Mangalyaan-1, GSLVMKIII, GSLV, PSLV, and ASLV launches. Atmospheric wind loads on the launch vehicle are derived from T-30 minutes for precise control of vehicle trajectory. The fine variations in wind profiles are closely observed for T-15 days and half-an-hourly winds variations are monitored for 12 hours on the launch day.*

The high power 53-MHz Mesosphere-Stratosphere-Troposphere (MST) Radar is the second largest powerful radar next to the Jicamarca radar. The radar has 1024 Yagi-Uda antennas and vacuum triode based transmitters, which provides a total peak power of 2.5 MW, high sensitive receiver, digital signal processing unit and PC based radar control system. The Radar is designed to study winds, waves and turbulence in the troposphere, stratosphere, mesosphere and plasma irregularities and electrodynamics in the ionosphere. It has been providing estimates of atmospheric parameters with very high resolution on a continuous basis. It is being used as a research workhorse in the investigation of atmospheric dynamics andmeso-scale phenomena and resulted in many publications. The radar has undergone various upgrades time to time to catch up with the fast changing digital technology and at present active array up-gradation is at the final stage. Multi-receiver experiments are planned in future in the modes of Spaced Antenna and Radar Interferometry/Imaging analysis for in-beam imaging of refractive index field and winds.

NARL has developed two lower atmospheric wind profiling (LAWP) radars, at 1280 MHz, for lower atmosphere dynamics studies. These radars, developed indigenously and first of its kind in India, are designed with innovative technological features that include simplified active aperture, passive calibration-free Butler Beam Forming Network (BFN),

pulse compression scheme and direct IF digital receiver. Simplified active aperture comprises of a planar microstrip patch antenna array in which each element is fed directly by a dedicated low power solid-state transmit-receive (TR) module.

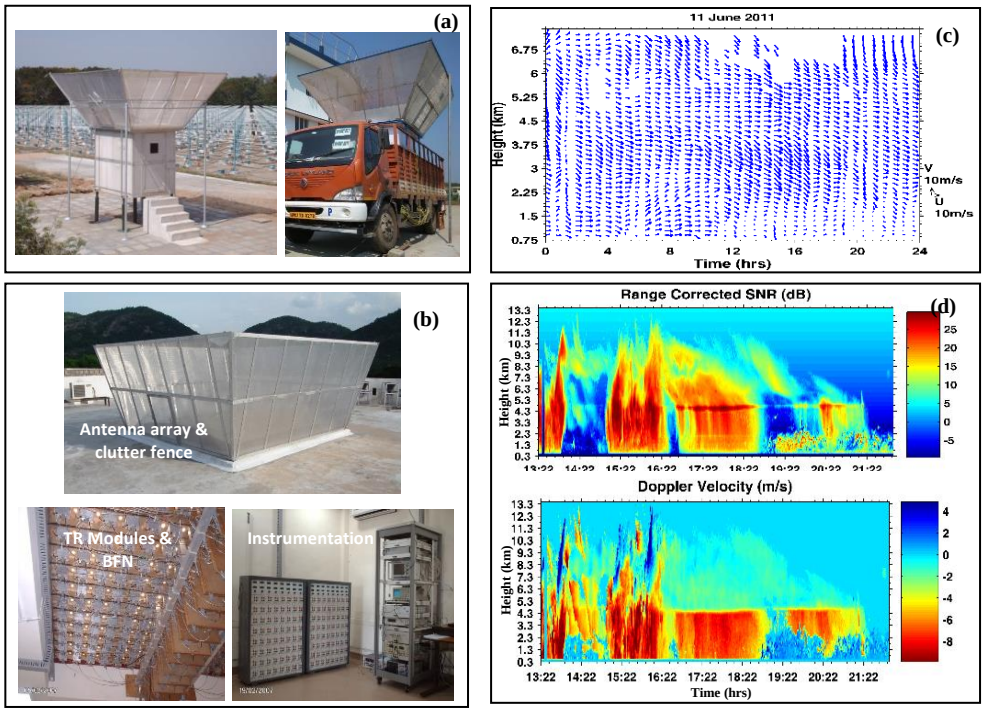


Figure 2. *(a) The transportable 8x8 LAWP radar, (b) 16x16 LAWP radar at NARL, (c) Diurnal wind measured on June 11, 2011 and (d) RTI (top) and RTV (bottom) plots showing the precipitation on July 05, 2010. (JAOT2011; JAOT 2012)*

TR modules are developed with COTS communication components, making them low cost and affordable. Of these two radars, one is transportable with 8x8 array and the other is stationary with 16x16 array. Both radars are scientifically validated. Transportable radar is under operation since May 2010 and stationary radar is under operation since April 2011. These radars operate in Doppler Beam swinging mode and are providing winds from 300 m onwards to 4 -5 km and supplement MST radar in the lower height region. During rain, the radar provides data upto ~12-13 km, and is a potential tool to study convection/precipitation. Some of the scientific applications include research studies like ABL Dynamics, Interaction between the ABL and the free troposphere, Vertical profiles of precipitation, Bright band Characterization, Rain/Cloud drop size distribution etc. Transportable LAWP has been deployed at IGCAR, Kalpakam in September 2010 and was operated there successfully, for 5 months period. Recently, in January 2015, it has been transported to CUSAT, Cochin, for validating the radar developed at CUSAT and was operated from vehicle itself for 3 days (09-11 January) and has proven its capability.The know-how of the transportable LAWP technology is being offered by ISRO for transfer to entrepreneurs/industry in India.

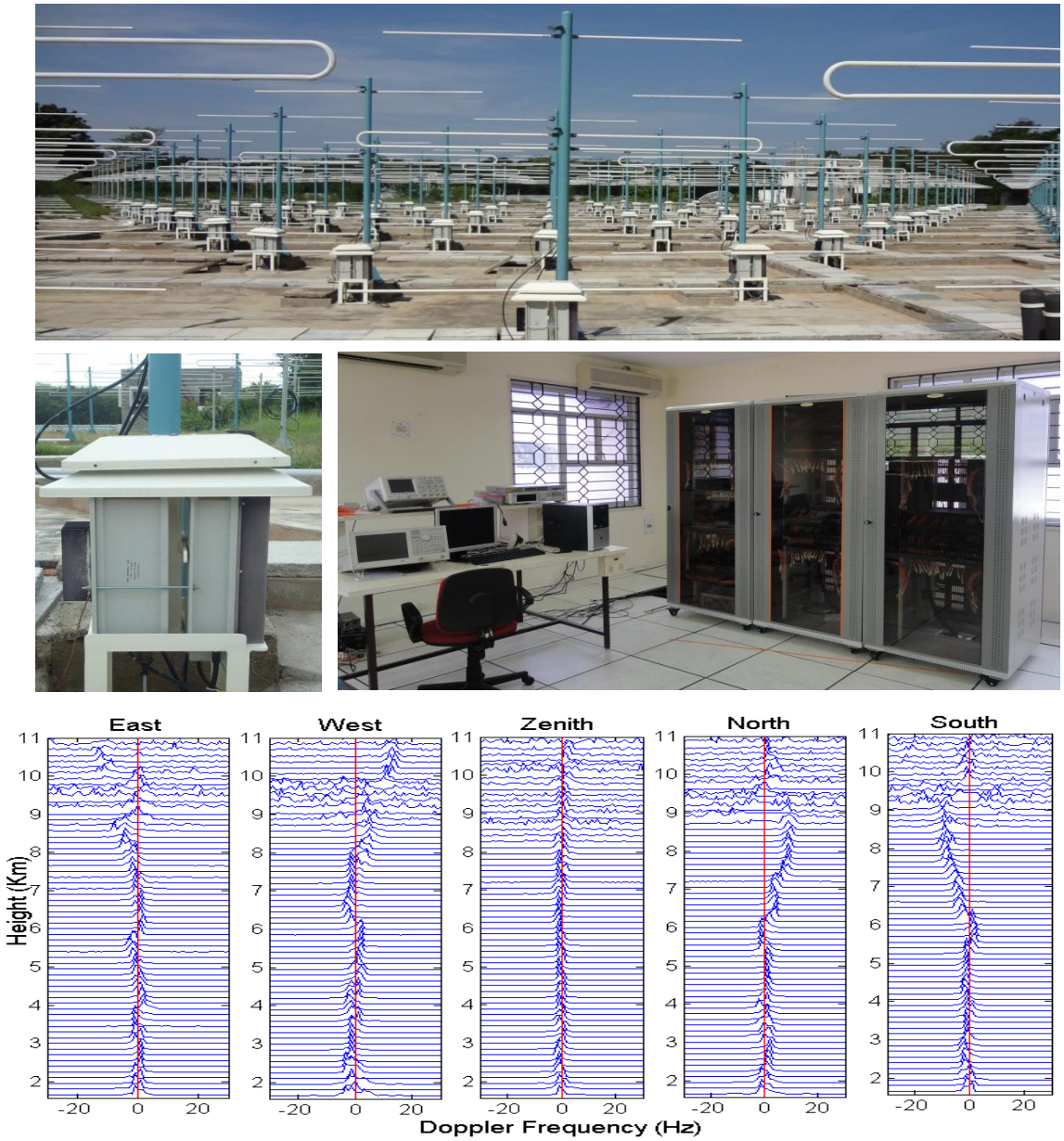


Figure 3. *Photographs of the pilot active phased antenna array (top), individual TR Module (middle left) and Control & Instrumentation (middle right), the sample Range-Doppler spectra observed on7th March 2013(bottom).*

A pilot 53 MHz 133-element active phased array radar has been developed with an objective to validate the technology concepts like out-door installation of solid-state transmit-receive modules, beam steering, optical fiber network based control, interface and monitoring of the TR modules etc. This system is developed as a precursor R&D activity for the ultimate up-gradation of the existing 1024-element MST radar into a full-fledged active phased array system. The system comprises of 133-elememt Yagi antenna array, 1-kW solid state TR modules, exciter, back-end receiver, Digital receiver and radar controller. The technological concepts have been successfully demonstrated with this pilot radar and the up-gradation of main MST radar system is taken up which is at the final stage of realization.

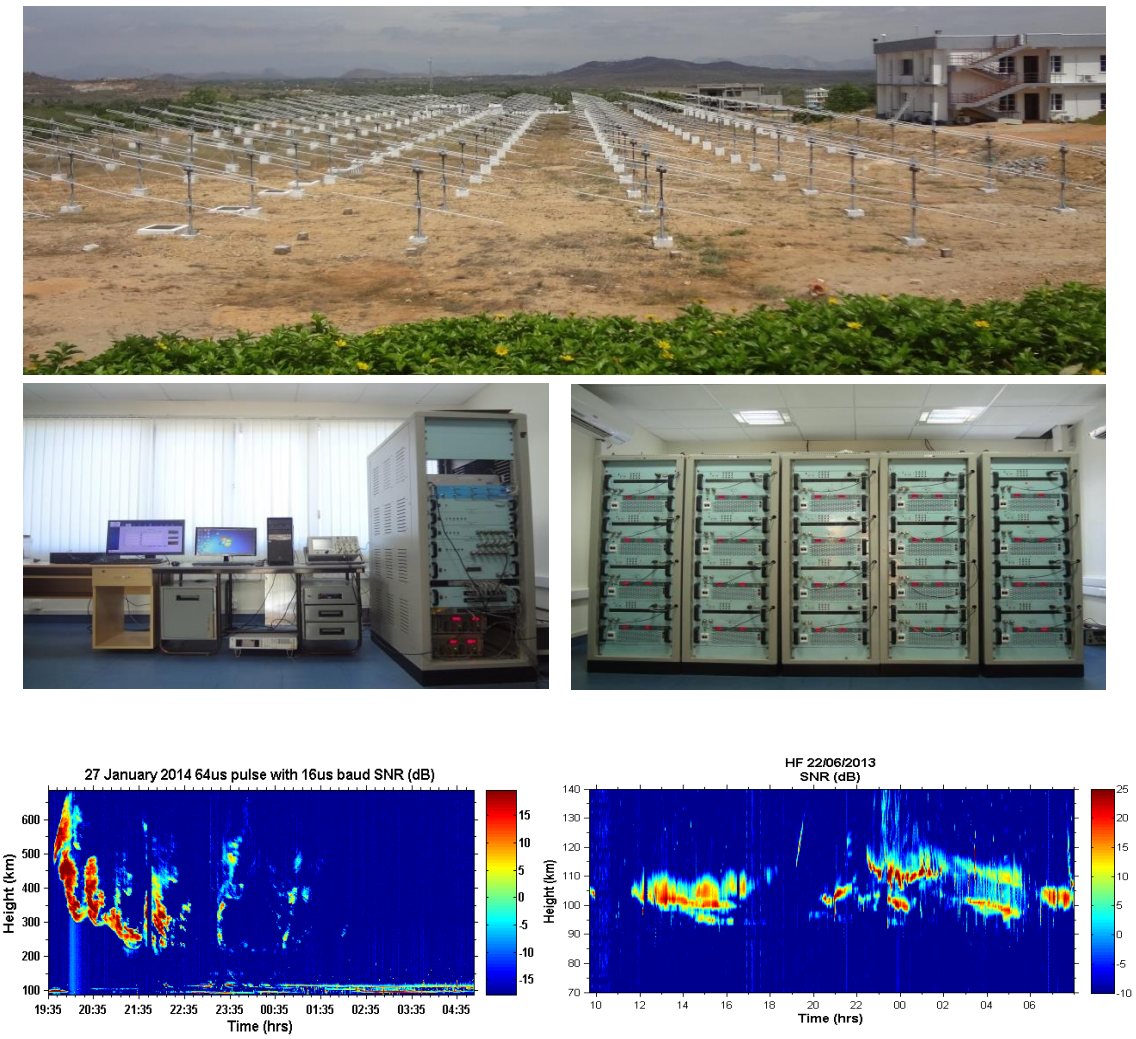


Figure 4. *30-MHz coherent Back scatter Radar is a unique modular radar designed to operate round-the-clock with in-house expertise and developed indigenously using state-of-the-art technologies with multi-receiver interferometry, beam agility, and aperiodic pulsing schemes for high resolution spatio-temporal mapping of ionospheric irregularities, meteor and space weather research. The photograph shows HF Radar antenna array (top), control room (middle left), transmit-receive room (middle right), the sample observations of Spread-F event (bottom left) and E-region for 24hrs (bottom right).*

To characterize the low latitude ionospheric irregularities and their spatial and temporal variations and develop an in-depth understanding on the governing physical processes, NARL has developed a new 30-MHz radar for dedicated probing of ionosphere and meteor showers which willstrengthen the Ionosphere research activities. This system comprises of 160 numbers of 14^{o}tilted two-element Yagi antennas arranged in a 20x8 matrix over an area of 112m x 56m. A total peak power of 150 kW is generated by 20 numbers of 7.5-kW solid-state TR Modules, each feeding a row of 8 antenna elements in North-South direction. The beam is fixed at 14^{o} due North and can be scanned upto ±45^{o} in the East-West direction. The system is made operational in 2013 and high quality observations of ionospheric E and F regions are being made.

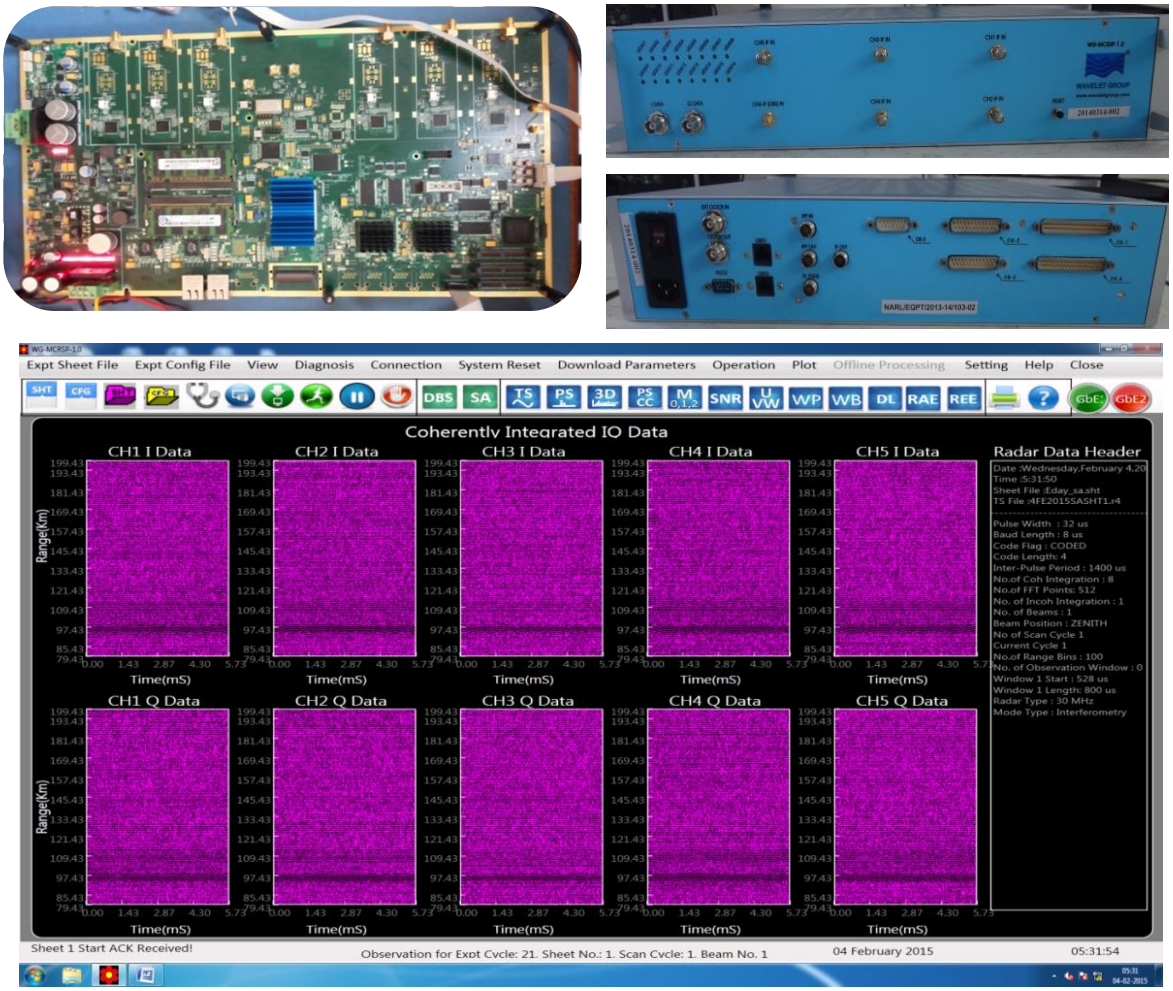


Figure 5. *Multi-channel digital receiver has been developed to facilitate radar operation in multi-mode in addition to the present Doppler Beam Swinging (DBS) technique. It is realized with a 24 layer board with inbuilt signal processing capability. One channel is dedicated for the standard DBS mode whereas up to five channels are available for experimental modes like spaced antenna (SA), radar interferometry (RI), coherent radar imaging (CRI) etc.*

Way Forward (The group will be involved in the following activities)

- Realization of a fully functional Active phased array MST Radar
- Incorporating incoherent Scatter technique in the Active Phased Array MST Radar for ionospheric studies
- Augmentation of 30-MHz radar system for Meteor related studies.
- Development of E-Scan Doppler Weather radar
- Development of in-house digital receiver with COTS board for atmospheric radars.
- Development of a low cost 445 MHz Spaced antenna wind profiler.
- Establishing a network of low cost spaced antenna wind profilers in the country for monitoring lower atmosphere and supporting weatherprediction.
- Development of software for multi-receiver data processing for applications like imaging, PBS, tracking etc.

- Development of data quality control software for atmospheric radars.
- Development of in-house microwave radiometer.
- Strengthening the laboratory with advanced test equipment, to facilitate R&D activities, maintenance, augmentation and up-keeping of the radars.

Work Plan

- Up-gradation of MST Radar into a fully Active phased array MST Radar is at the final stage of implementation and is expected to be completed by Dec 2015.
- Incorporating In-coherent Scatter technique with Active Phased Array MST Radar has been initiated and is expected to be accomplished by Oct 2016.
- Meteor radar system will be realized with available instrumentations for 30-MHz radar. Antenna system, feeder network and hybrids are being realized. The necessary algorithms developments are initiated and will be accomplished by Jul 2017.
- Development of E-Scan Weather radar is planned as 14^{th} Five year plan activity.
- Towards realization of the In-house digital receiver, COTS board has been procured and processing is implemented offline. Online processing software is being developed.
- System design and development of the 445 MHz spaced antenna wind profiler/Imaging radar is under process.
- After the successful completion of the 445 MHz spaced antenna wind profiler establishment of a network of wind profilers will be initiated.
- Multi-receiver data processing algorithms will be developed and validated with the simulated data. They will be applied to the multi-receive channel data that will be collected with the active array MST radar and other radars.
- Design study will be done for the realization of microwave radiometer.

7.2 Ionospheric and Space Physics Group

Group Members

Head: Dr. A K Patra, M. Sc. Ph. D., Scientist/Engineer-SG

Scientific /Technical Staff

Dr. Alok Taori, M. Sc., Ph. D., Scientist/Engineer-SE
Dr. Nirvikar Dashora, M. Sc., M. Tech., Ph. D., Scientist/Engineer-SE
Mr. Sumit Singh Rana, B. Tech., Scientist/Engineer-SC
Mr. Himanshu Sekhar Sethi, B. Tech., Scientist/Engineer-SC

Research Fellows, PDFs, RAs

Mr. P Pavan Chaitanya, M. Sc., M. Tech.,RA
Mr. M Sivakandan, M. Sc., SRF
Ms. Sunanda Suresh, M. Sc., SRF

Photograph: A collage of airglow imager, GPS receiver and 30 MHz radar

Objectives

Developing understanding on the low latitude ionospheric electrodynamics, variabilities due to forcing from the sun and the lower atmosphere, plasma irregularities and instabilities, space weather effects through observations and numerical simulation/modelling and defining the future state of the ionosphere.

Major Research Accomplishments

Equatorial plasma bubble: precursor, seeding and coupling

- ✓ Using radar observations, unusual down-drafting F region plasma structures extending down to the E region have been revealed. Enhanced down-drafting plasma flow in these structures was shown to be due to polarization electric field associated with F region plasma depletion. (Radio Sci 1997)
- ✓ Low latitude valley region irregularities have been found to occur independent of ESF irregularities. Their occurrence pattern and local time preference are reminiscent of intermediate layers, formed by meridional wind shear associated with semidiurnal wind. It has also been shown that the valley region irregularities that occur in association with F region irregularities have similar spatial structures, temporal variation and drift velocity as that of F region, providing clear evidence on the strong control of the F region fields on the generation and movement of the valley region irregularities and structures. (GRL 2000; JGR 2005, 2007)
- ✓ Disruption of the E region irregularities in association with the growth phase of the plasma bubbles is a commonly observed feature at Gadanki, India and Kototabang, Indonesia. It has been shown that the weakening and disappearance of E region signals are directly coupled with the F region electric fields associated with spread F over the equator. It is shown that these fields when map to the low latitude E region inhibit the growth of the E region instability processes. A Physical model describing the polarization processes generating large electric field inside the bubble and its role on the underlying E region along the magnetic field has been given. (GRL 2004, 2005)
- ✓ Using HF and VHF radars, it has been shown that significant velocity dispersion of F region irregularities at different scale sizes exist. (JGR 2005)
- ✓ A relation between mesospheric gravity wave and equatorial plasma bubble occurrence has been found and the gravity wave seeding hypothesis for the formation of plasma bubble has been advanced. (JGR 2011)
- ✓ A novel algorithm for real-time detection of depletions in GPS-TEC has been developed and a software implementation has been accepted by ISRO- GAGAN. Definitions of depletion, scintillations and geomagnetic storms have been provided for ISRO-

GAGANproject. An analysis covering 3-dimensional statistics of TEC depletions with regard to latitude, time and depth of TEC depletions has been developed for ISRO-GAGAN project.(ISAC Report 2011)

- ✓ A new innovative and inexpensive airglow photometer technique to detect zonal plasma structures as a precursor has been demonstrated. The observed plasma structures show a close linkage to radar plumes underlining their role in seeding equatorial plasma bubble. Scale sizes of the plasma structures, estimated using the airglow observations, agree with the often shout after gravity wave scales needed for seeding. Measurements made using the new scheme along with other radio experiments provide faithful predictors for the occurrence of equatorial plasma bubble. (JGR 2012)
- ✓ The role of low latitude sporadic E in the E-F region coupled electrodynamics has beeninvestigated in detail using observations and numerical simulation. Role of sporadic E on the inhibition of equatorial plasma bubble has been clearly observed. It has also been shown that field-line integrated conductivity computed using E and F layer observations have inhibited the growth rate of the RT instability in simulation experiments. It has been suggested that the role of sporadic E in influencing the formation of equatorial plasma bubble should be considered in the scintillation forecasting strategy. (JGR 2013a,b)
- ✓ Using the recently established Gadanki Ionospheric Radar Interferometer (GIRI), it has become possible to study spatial evolution of equatorial plasma bubble. Figure 6 shows three azimuth-sector maps of radar backscatter observed on 5 March 2014. These maps represent variations of SNR with height and zonal distance from the radar (obtained from azimuth angle) and illustrate formation of FAI in the neighborhood of Gadanki longitude and their eastward motion. (JGR 2014)

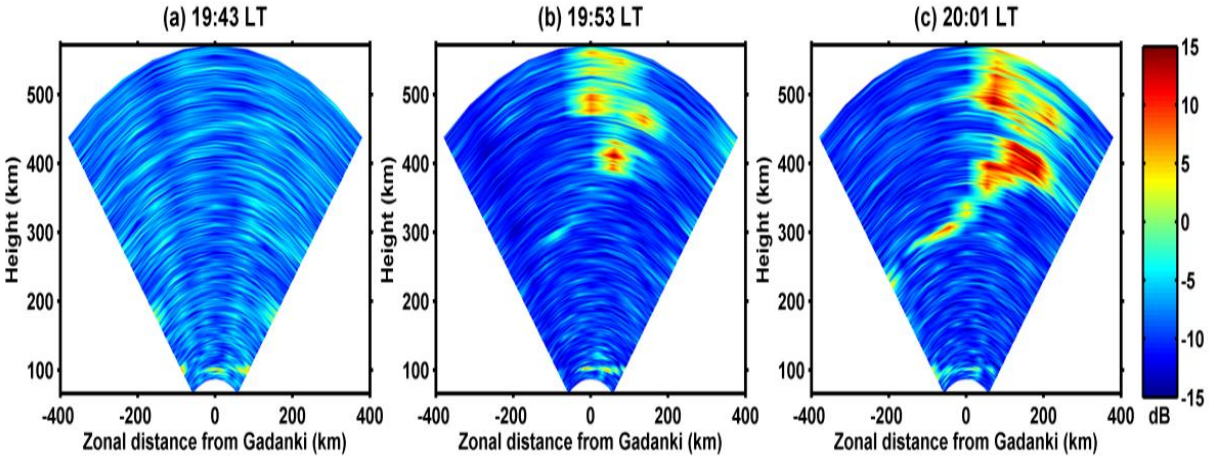


Figure 6.*Azimuth-sector SNR map showing spatial variations of F region FAI observed at (a) 19:43, (b) 19:53 and (c) 20:01 LT on 5 March 2014, demonstrating the growth of the plume.*

- ✓ Occurrence and non-occurrence of irregularities at the equator and off-equator in between the E and F region during the plasma bubble development has been

investigated. Using plate capacitor analogy of equatorial plasma bubble, fringe fields in the valley region have been computed and it is shown that magnitude of fringe field decreases with latitude owing to inclined magnetic field geometry with latitude. Further, it has been shown that updrafting plasma irregularities in the valley region over the equator are generated when vertical wind perturbation is present. (JGR 2014, 2015)

Equatorial ionospheric electrodynamics and variabilities

- ✓ Opportunity of Solar Eclipse of 22 July 2009 has been utilized to first time bring forth that a morning solar eclipse can also change the TEC and F region electron density at all altitudes. (JASTP 2010, 2011)
- ✓ A climatological study of low latitude ionosphere spanning two solar cycles from 19998 to 2015 has revealed that source mechanisms of long term changes in ionosphere at smallerscales are still not fully known as well as those at QBO scales with regard to forcing by solar radiation on ionospheric TEC (Fig. 7). A novel method to determine the solar high and low activity with regard to ionosphericvaribility has been proposed. Forcings due to ExB drift, meridional wind and due to wave-tides coupling from lower atmosphere hold the key to lead further. (JASTP 2010; JGR 2015)

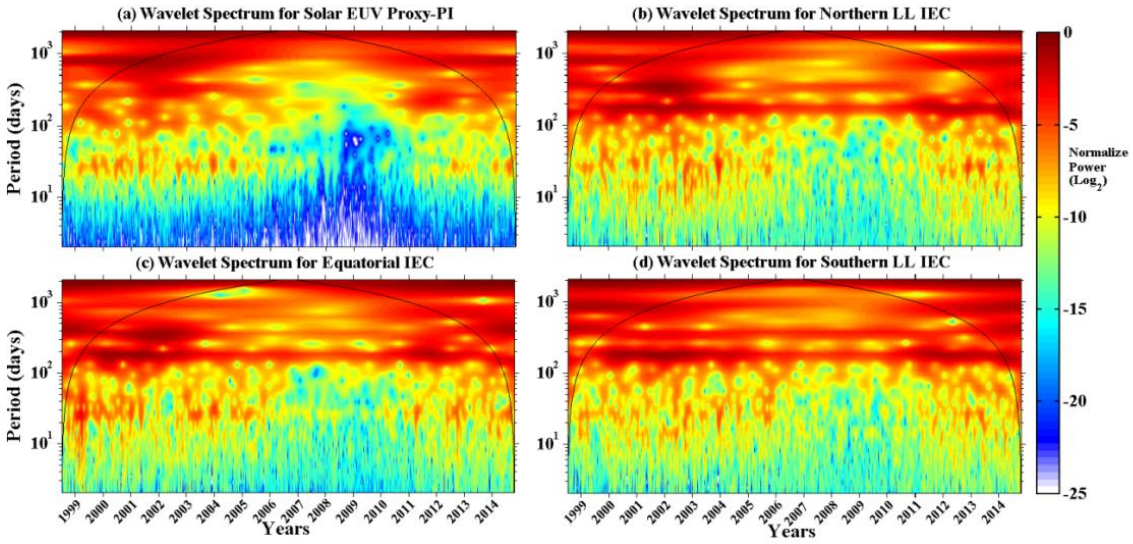

(a) Wavelet Spectrum for Solar EUV Proxy-PI
(b) Wavelet Spectrum for Northern LL IEC
(c) Wavelet Spectrum for Equatorial IEC
(d) Wavelet Spectrum for Southern LL IEC
Period (days)
Years
Normalize Power (Log2)

Figure 7*. Wavelet spectrogramsof (a) solar EUV flux from 1998-2015 given with ionospheric electron content (IEC) over three locations (b) northern (16^o N geomagnetic)(c) equatorial (dip equator) and (d) southern (16^o S geomagnetic). (JGR 2015)*

- ✓ Local time and seasonal variabilities of F_2- and F_3- layer parameters during different solar conditionsshowed a strong summer-winter contrast in the F_3 layer, which has been explained using **ExB** drift and meridional wind in SUPIM model for the first time in the Indian sector. (JGR 2013)

- ✓ Using the daytime 150 km radar echoes, **E**x**B** drifts have been estimated and validated using satellite observations. A detailed study has been conducted for the India-Indonesia sector using radar, satellite and model and the roles of planetary wave, tide and gravity waves have been outlined to understand longitudinal, day-to-day and short-period variations in **E**x**B** drift. (JGR 2014a,b)
- ✓ Quiet time variations of low latitude electrodynamics linked with high latitude SSW have been investigated. SSW induced variations have lead to strong semidiurnal variations in electric field and electrojet current. Modified electric field has resulted in anomalous behavior of the E and F regions and generation of late night plasma irregularities. (JGR 2014)

Response of low latitude ionosphere to Space weather events

- ✓ Large Enhancement in daytime GPS-TEC has been observed with VTEC levels reaching to more than 100% of quiet time values. Occurrence of immmediate effects (1-2 hours) are explained with a new hypotheses under local low latitude response to prompt penetration electric fields (PPEF). The occurrence of delayed effects (3-4 hours) are explained as a combined effect of PPEF and development of EIA in presence of TADs. (Ann. Geophys. 2009)
- ✓ Using GPS-TEC from three longitudes 25 degrees apart it was found that PPEF immediately produces enhanced levels of TEC in latitudes around 20-25^{o} N. This proved local low latitude response of PPEF. Further the presence of westward PPEF during southward directed IMF-Bz in daytimewas reported for the first time. (JGR 2011)
- ✓ First time observations of effect of TADs as TIDs up to equatorial latitudes in various longitudes using GPS-TEC from multiple stations highlighted that mechanical effects of TADs can modulates the TEC by 5-8 TECU. (Ann. Geophys. 2011; JASTP 2011)

Daytime 150-km echoing phenomenon

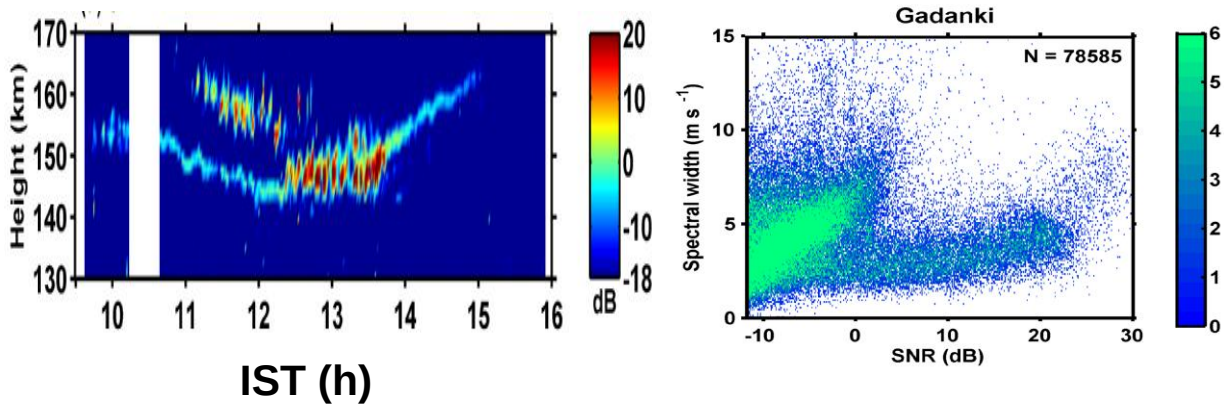


Figure 8. *(Left) Height time SNR map of 150 km echoes displaying necklace and descending echoing layers. (Right) Two-dimensional histogram of SNR and spectral width illustrating population density of two types of echoes observed by the MST radar.*

- ✓ Successful detection of 150 km echoes from off-equatorial radars (Gadanki, Kototabang and Sanya) provided new insight on the puzzling 150 km echoing phenomenon.The plausible roles of photochemistry and metallic ions in the plasma instability process have been revealed through observations made utilizing the opportunity provided by the solar eclipse 2010. Descending pattern of 150 km echoes reminiscent of intermediate layer has been brought out for the first time underlining the additional role of tides and gravity waves in the echoing phenomenon.Identified two types of 150 km echoes, which lead to consider incoherent scattering as one of the potential candidates involved in the echoing phenomenon. These findings have led to consider neutral dynamically controlled metallic ion layers, photochemistry and plasma instability including some kind of incoherent scattering in the echoing process. (JGR 2006, 2011a, b; GRL 2007)

E-region plasma irregularities

- ✓ E region FAI over low latitude are shown to be vastly different from those of electrojet and midlatitude. Analysis clearly suggests that zonal component of tidal wind plays a crucial role in forming tidal ion layers, which become unstable to gradient drift instability with background electric field or/and zonal neutral wind generating E region FAI.It has also been shown that Sporadic E blob results in strong plasma irregularities resulting in daytime scintillation of radio waves passing through the ionosphere. (JGR 2009, 2012)
- ✓ It has been demonstrated for the first time that plasma irregularities can be excited in the E region by a solar eclipse. It has also been shown that thin metallic ion layers in the E region become visible through a coherent radar during a solar eclipse, demonstrating the potential of a coherent radar to study the ion layers. (GRL 2009)
- ✓ It has been revealed that the E region plasma irregularities can have planetary scale variabilities quite similar to those of neural parameters. Further it has been shown that these variabilities coexist with the planetary scale variability observed in the SABER temperature, underlining neutral-plasma coupling. (JGR 2009)
- ✓ Using radar observations of lower E region irregularity velocities and meteor winds, it has been shown that the FAI drift and winds measured by meteor radar agree very well. The height of FAI occurrence is found to be related to westward wind suggesting the role of wind driven gradient drift instability. (JGR 2007)
- ✓ Low latitude QP echoes have been investigated using observations and numerical simulation. Plasma blobs formed by gravity waves are shown to be source of QP echoes. This mechanism overcomes the difficulty faced by KH instability. (JGR 2008 a,b)
- ✓ Field-aligned plasma structures, resembling to large-scale primary gradient drift waves, in the collision dominated lower E region, where the conventional plasma instability processes do not operate, have been discovered. Based on the structures and dynamics associated with these irregularities and related analysis, these structures have been explained in terms of Kelvin-Helmholtz instability coupled with secondary plasma instability. (JGR 2008; GRL 2009)

✓ East-west asymmetry of the spectral parameters of the type-II electrojet irregularities have been explained successfully for the first time using the premises of the km-scale primary gradient drift waves. (JGR 2005)

Mesospheric wave propagation and breaking

✓ Mesosphere is the gateway of neutral wave inputs into the thermosphere, hence the characterization of wave properties at mesospheric altitudes. In this direction, propagation of gravity waves and subsequent breaking have been studied using airglow imager in the upper mesosphere (Fig. 9).

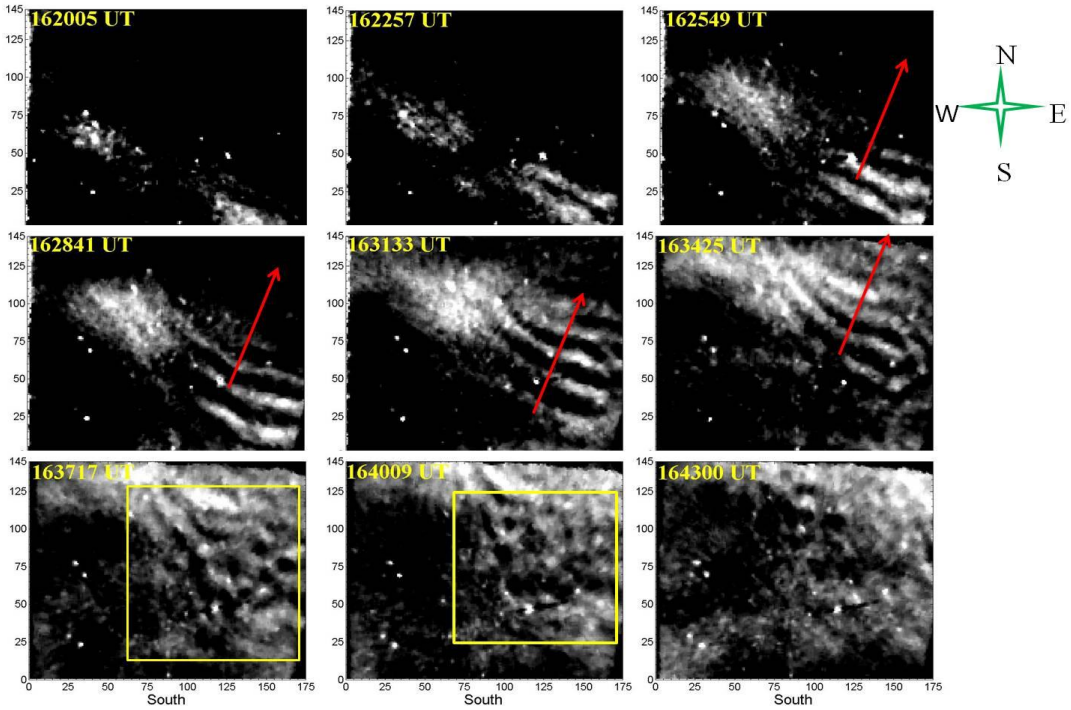


Figure 9. *Sequence of O(^{1}S) images displaying the gravity wave event from the start to finish. The time of measurement is shown as yellow fonts at top-left corner of each image while the direction of wave propagation is shown as red arrows. Note that within 20 min, the wavefronts turned into the turbulence-dominated region highlighted as yellow boxes. (JGR 2015)*

Propagation characteristics of these gravity waves from 40 to 95 kmhave been investigated for the first time,using simultaneous Rayleigh lidar and mesospheric OH and O_2 airglow measurements.It has been shown that the amplitude of these waves undergo changes during their upward propagation. Signature of these waves has been studied in temperature fields and their characteristics have been studied based on relative amplitudes in temperature and density fields. (ACP 2015)

✓ Improvement of Rayleigh lidar temperature retrieval method: Height extent of temperature profile using *Rayleigh lidar*backscatter has been enhanced, *for the first time in the world,* using mesospheric O_2 temperature as seed at 100 km. (Ann. Geophys. 2012)

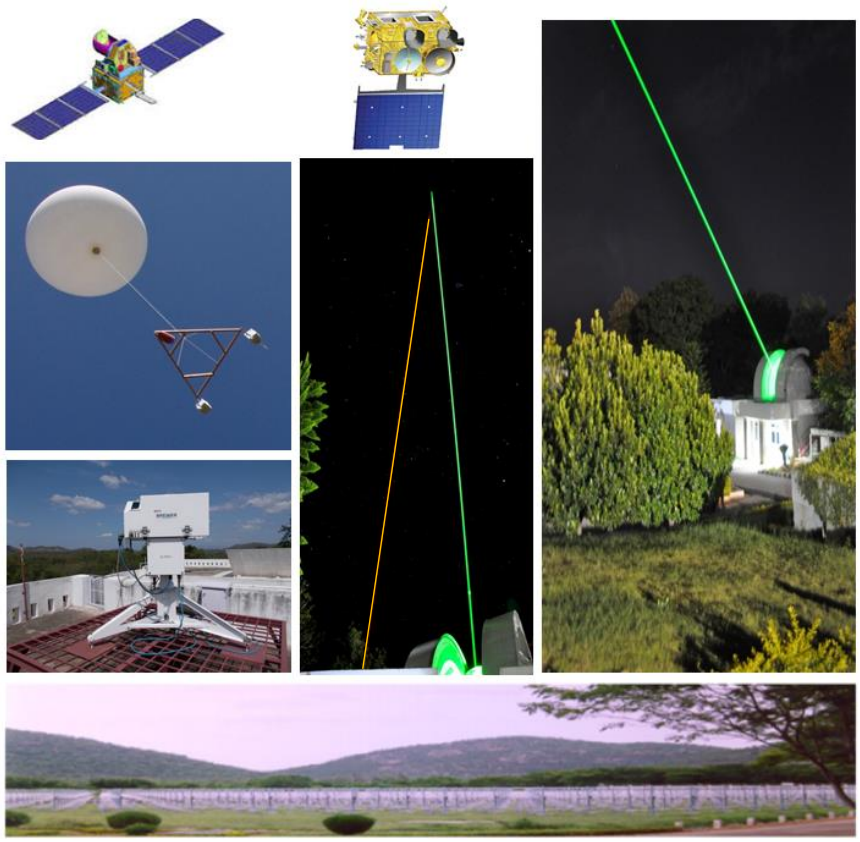
Way Forward (The group will be addressing the following questions)

- How does the equatorial ionosphere respond to lower atmospheric forcing from below and lateral forcing from high/mid latitudes?
- How does equatorial ionosphere respond to space weather events?
- How to forecast the occurrence of equatorial plasma bubble (EPB) and its effect on satellite communications/navigation?

Work Plan

- The active array MST radar will be augmented with incoherent scatter capability to measure electron density, ion composition, ion and electron temperatures, **E**x**B** drifts and meridional wind.
- High resolution measurements using GNSS network along latitude and longitude will be developed for TEC and scintillation studies. A high resolution network around Gadanki will be developed for 3-D ionospheric imaging.
- SAMI3 model will be augmented with GCM. India specific data assimilative schemes would be explored.
- A long database will be built up to provide a detailed statistics on the gravity wave propagation characteristics, including their amplitude, direction and momentum fluxes.
- Simultaneous observations using radio and airglow techniques along with model computation will be performed towards understanding F-region wavelike perturbations and EPB relations.
- A low inclination equatorial satellite experiment is being planned in collaboration with other institutes to investigate thermosphere-ionosphere processes including EPB.
- A lightning detection camera along with field mill and spectrometry experiments will be established.

7.3 Atmospheric Structure and Dynamics Group (ASDG)



Group Members

Head: Dr. K Raghunath, ME, Ph D, Scientist/Engineer-SF

Scientific /Technical Staff

Dr. M Venkat Ratnam, M Sc, Ph D, Scientist/Engineer-SF
Dr. T K Ramkumar, M Sc, Ph D, Scientist/Engineer-SE
Dr. S Sridharan, M Sc, Ph D, Scientist/Engineer-SE
Ms. M Anjani Sindhusha, B Tech, Scientist/Engineer-SC
Mr.Ch Yaswanth, B Tech, Scientist/Engineer-SC

Research Fellows, PDFs, RAs

Ms. M Sandhya, Ms. M Pramitha, Mr. A Hemant Kumar, Mr. S T Akhil Raj,
Ms. Oindrila Nath, Ms. HimaBindu, Ms. Priyanka Ghosh (SRFs)
Dr. K Ramesh, M. Sc., Ph.D., (RA)

Photograph: Collage of MST radar, Brewer Spectrophotometer, GPS Radiosonde, Ozonesonde, Frost Point Hygrometer, MeghaTropiques, INSAT-3D, Rayleigh/Mie lidar, Sodium lidar and Doppler Lidar

Objectives

To develop capability to understand and predict the role of middle atmosphere (10-100 km) on the lower and upper atmosphere and vice versa through well planned experiments and modeling.

Effective utilization of Indian satellite observations by participating closely in Data Retrieval and Validation teams of ISRO.

To investigate structure and dynamics of the lower and middle atmosphere including, convection, wave dynamics, turbulence, tropical tropopause and STE processes, Stratospheric Sudden Warming, mesopause characteristics, long-term trends using ground based, satellite measurementsand modeling.

Major Research Accomplishments

- ✓ With the onset of the sudden stratospheric warming (SSW), decreased planetary wave activity, enhanced gravity wave activity and change of mesospheric circulation from poleward to equatorward have been first reported from low-latitudes. (GRL 2009)
- ✓ Limitations in the WMO definition for the identification of multiple tropopauses over tropical latitudes are found and its definition is re-defined based on cold point (CPT) which has more physical significance. (JGR 2010)
- ✓ MST radar observations showed that strong unstable wind shear layers located near the tropopause are an important source of momentum and energy fluxes that contribute significantly to the middle atmospheric dynamics in terms of gravity waves.(JGR 2010)
- ✓ For the first time, the MST radar (53 MHz) observations showed existence of layers of polarized refractive-index structures in the 10 to 15 km altitude region, which are thought of associated with distinct microphysical properties of the Global Electric Circuit (GEC) influenced atmospheric water vapor scatterers (Fig. 10). (JGR 2010)
- ✓ Long-term tendencies and variabilities of middle atmospheric parameters are reported. It is noteworthy that there is a decreasing trend in the northward upper mesospheric winds. It is attributed to long-term change in circulation due to increase of CO2 and selective filtering of gravity wave activity. (JGR 2010)
- ✓ The mesopause altitude in the tropical latitudes is observed to be always close to ~100 km without significant seasonal variation. (JGR 2010)
- ✓ Radars with different operating frequencies and employing different techniques of Doppler and spaced antenna methods show an entirely different type of drift motions in the heights of 90 to100 km in the equatorial electrojet region.(JGR 2010)
- ✓ Intraseasonal oscillation had its origin in the tropical lower troposphere and propagated laterally and vertically to the upper mesosphere through the subtropical

latitudes by partial refraction and reflection processes about the subtropical westerly jet.(JGR 2011)

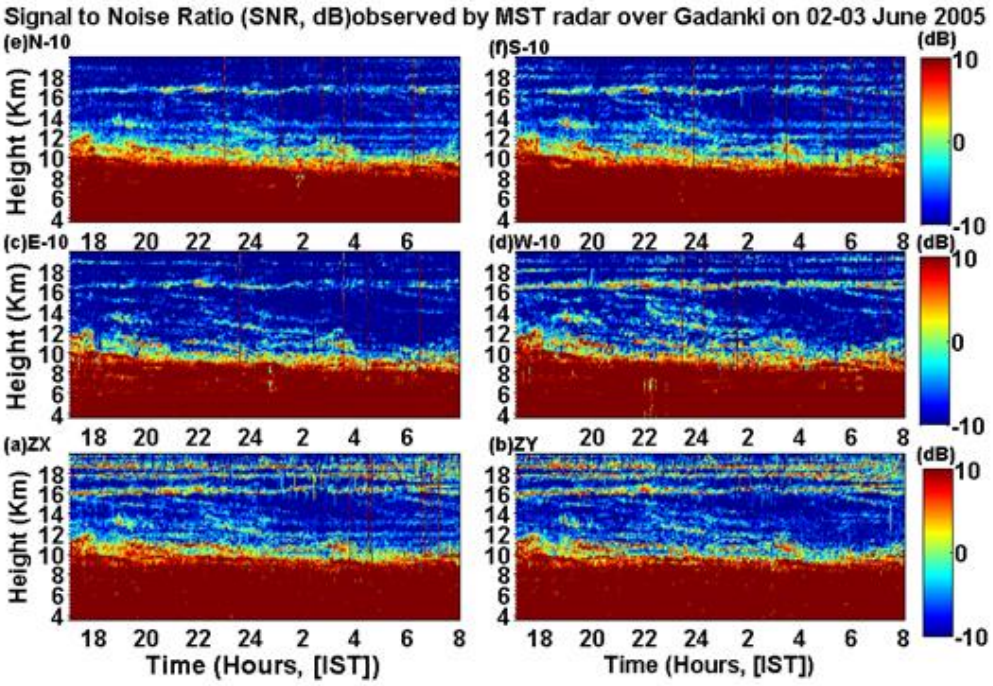


Figure 10*. Height versus time (112 s time interval) contour plots of signal to noise ratio in dB of received echoes by MST radar for zenith beam, Zx polarization(a),Zy polarization(b) , (c) 10° east, (d) 10° west, (e) 10° north, and (f) 10° south directions for the same period of 1700–0840 LT on 2–3 June 2005. (JGR 2010)*

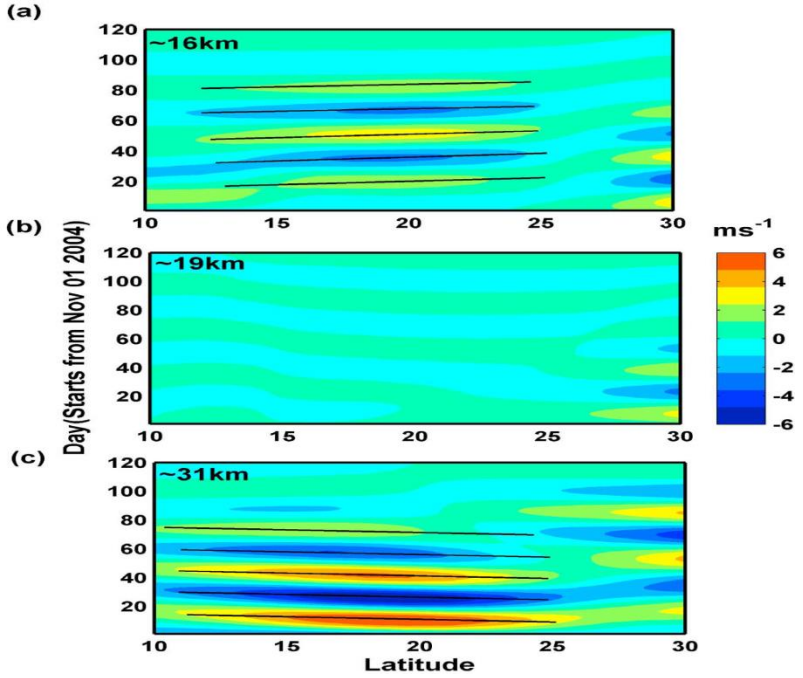


Figure 11.*ECMWF observation (Dec 2004 to Feb 2005) of instraseasonal oscillation (20-40 day oscillation) in zonal wind velocity propagating (a) from the equatorial to Northern subtropical region near the tropopause at ~16 km (b) no oscillation and (c) from the subtropical to the equatorial region in the stratosphere at ~31 km. (JGR 2011)*

- ✓ Both the convective and geostrophic adjustment processes in the troposphere play major role in the generation of inertia gravity waves emanated from tropical cyclones over the Bay of Bengal. (GRL 2008, JASTP 2011)
- ✓ A Fabry-Perot Interferometer based method was demonstrated to suppress background noise in daytime lidar measurements. (AG 2012)
- ✓ Stratospheric three-dimensional properties of a mountain wave event that occurred over the western Himalayan region at ~40 km height are investigated by using AIRS on board the Aqua and MLS on board the Aura satellite measurements. (JGR 2012)
- ✓ Increasing trend in TEJ intensity is found in the recent decade, unlike reported earlier using coarse resolution data (Fig. 12). (GRL 2013a)

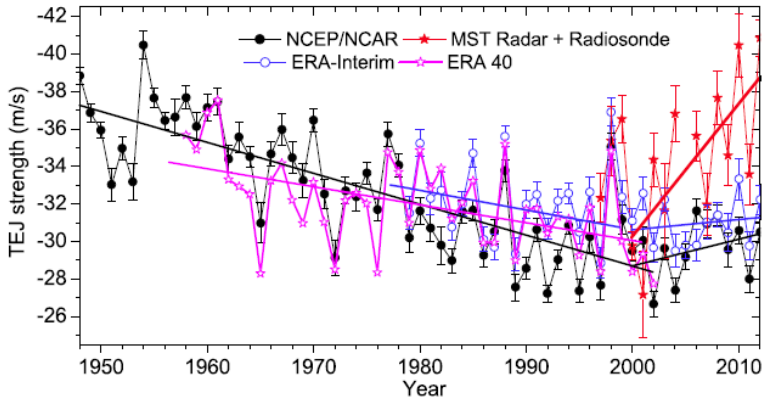


Figure 12. *Zonal wind at 100 hPa obtained from re-analyses data averaged over 10 to 20°N and 60 to 100°E. Zonal wind obtained from the MST radar and radiosonde is also shown. (GRL 2013a)*

- ✓ A decreasing trend in the zonal wind is found in mesosphere, changing from strong eastward winds during the 1970s to weak westward winds in recent years. Simulations of NCAR TIME-GCM also showed a similar change in the circulation when CO_2 in the atmosphere is doubled, suggesting role of anthropogenic changes in the dynamics of the mesosphere (Fig. 13). (GRL 2013b)

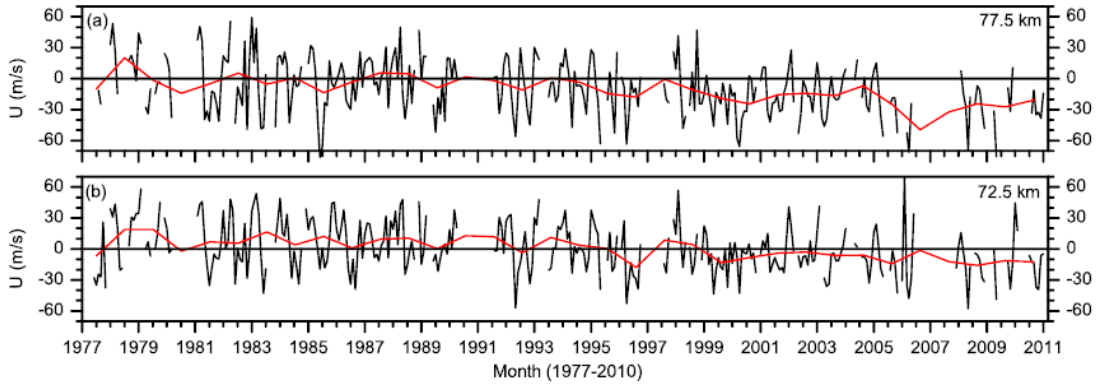


Figure 13. *Monthly mean zonal wind (black line) constructed using rocket (1977–1991), HRDI/UARS (1991–1999), and MST radar (1995–2010) at (a) 77.5 km (averaged between 75 and 80 km) and (b) 72.5 km (averaged between 70 and 75 km), respectively. The derived annual mean zonal wind (red line) from these observations is also shown. (GRL 2013b)*

- ✓ Influence of potential vorticity intrusion events on the development of convection, inhibition of the existing convection distribution of minor constituents, and the selective generation of equatorial waves has been shown. (AR 2013)
- ✓ The remarkable coupling between polar SSW events and the occurrence of afternoon counter-electrojet events in equatorial ionosphere has been established. The relative role of solar and lunar tides is demonstrated (Fig. 14). (JGR2013)

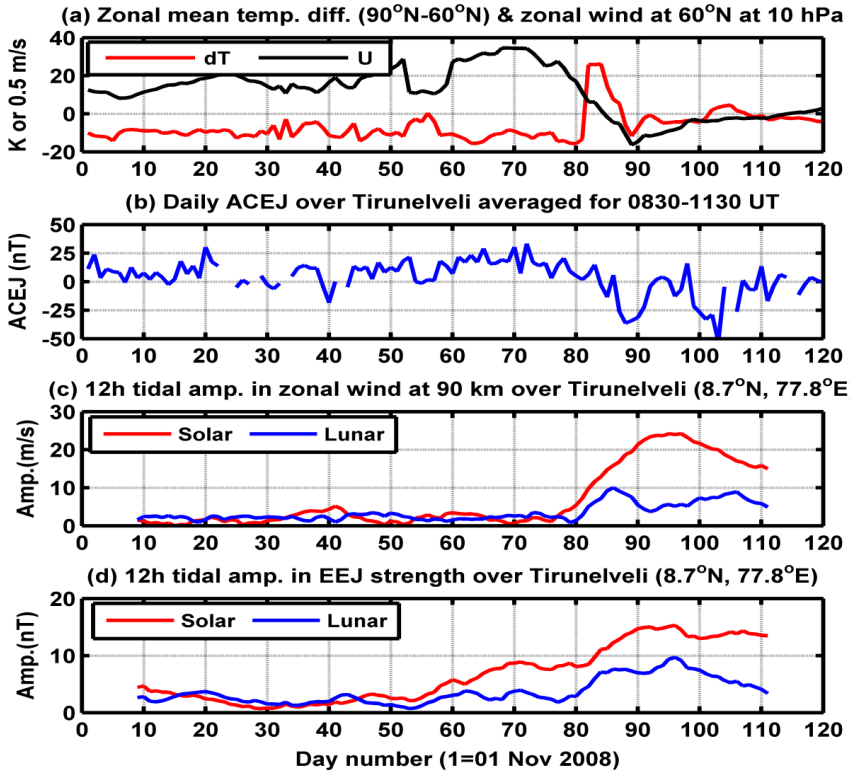

(a) Zonal mean temp. diff. (90°N-60°N) & zonal wind at 60°N at 10 hPa
K or 0.5 m/s
dT
U
(b) Daily ACEJ over Tirunelveli averaged for 0830-1130 UT
ACEJ (nT)
(c) 12h tidal amp. in zonal wind at 90 km over Tirunelveli (8.7°N, 77.8°E)
Amp.(m/s)
Solar
Lunar
(d) 12h tidal amp. in EEJ strength over Tirunelveli (8.7°N, 77.8°E)
Amp.(nT)
Day number (1=01 Nov 2008)

Figure 14*. a) Daily variation of zonal mean temperature difference between the latitudes 90°N and 60°N and zonal mean zonal wind at 60°N at 10 hPa pressure level; (b) daily afternoon CEJ strength computed by taking average of EEJ strength for 0830–1130 UT (c,d) solar and lunar semidiurnal tidal amplitudes (c) in zonal wind at 90 km and (d) EEJ strength over Tirunelveli for the time interval of 1–120 days starting from 1 November 2008*. (JGR 2013)

- ✓ Rayleigh Doppler system as research tool was developed for lower and middle atmosphere wind observations (Fig. 15). (2013)
- ✓ Persistent occurrence of thick cirrus clouds is observed in the Mie-lidar observations over Gadanki during almost entire SSW of 2009 event coinciding with the presence of high relative high humidity (40%) and low tropopause temperature. It is suggested that the deep convection triggered by the potential vorticity intrusion over the Indian sector. (JASTP 2013)
- ✓ The seeding mechanisms of quasi-periodic and descending radar echoes in the low-latitude ionosphere are investigated with particular reference to the role of tides and gravity waves. (JGR 2014)

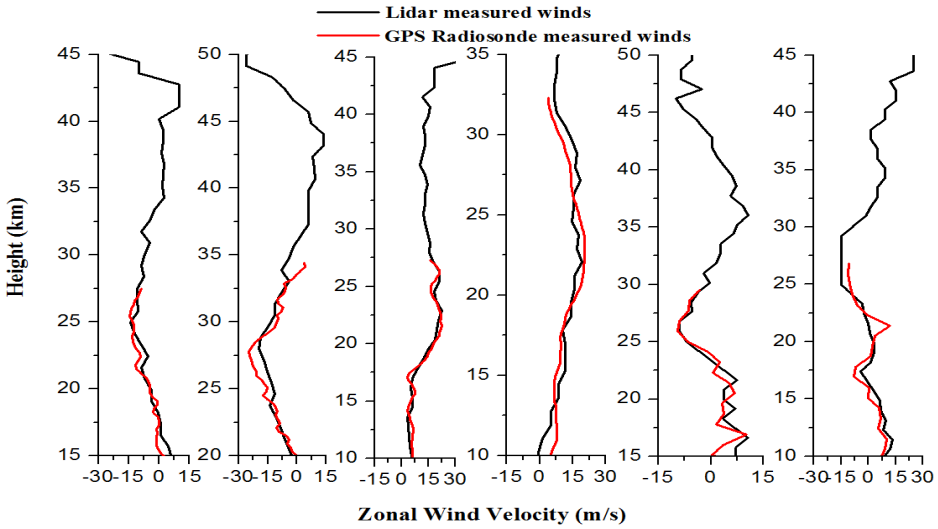


Figure 15*. Zonal winds as measured from Rayleigh Doppler lidar in the months of Dec., Jan., Feb., 2011, 2012. The experiment was conducted with 4 min time integration and 300m range resolution. The profiles are compared with Radiosonde winds at Gadanki. The system axis was tilted 20^{0}of zenith to obtain Zonal and Meridional winds at +/- 1.8 m/s accuracy.The correlation coefficient between lidar measured and Radiosonde measured winds was found to be 0.83*.

- ✓ A series of experiments conducted revealed that vertical winds are always upward in TTL suggesting that deep convection need not necessary for STE to occur (Fig. 16), large ozone mixing ratio in upper troposphere during ISM, large transport of WV into lower stratosphere is noticed. Good relation between cirrus clouds present in UTLS region and tropopause altitude is noticed. (JASTP 2014)

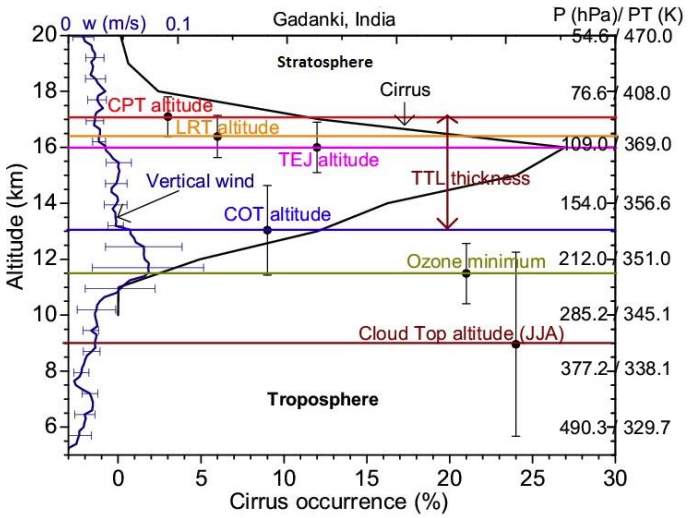


Figure 16.*Climatological values of various tropopause parameters observed over Gadanki using long-term radiosonde observations. The vertical wind obtained using MST radar is also shown (top left side). The climatological mean percentage occurrence of cirrus mean altitude obtained using collocated Mie Lidar during this period is also shown (bottom axis. (JASTP 2014)*

- ✓ Causative mechanisms of mesospheric inversion layers with special reference to chemical reactions have been demonstrated (Fig. 17). (JGR 2014)

- ✓ Influence of solar cycle and chemistry on the variability of tropical mesopausehas been revealed. (JGR 2015)

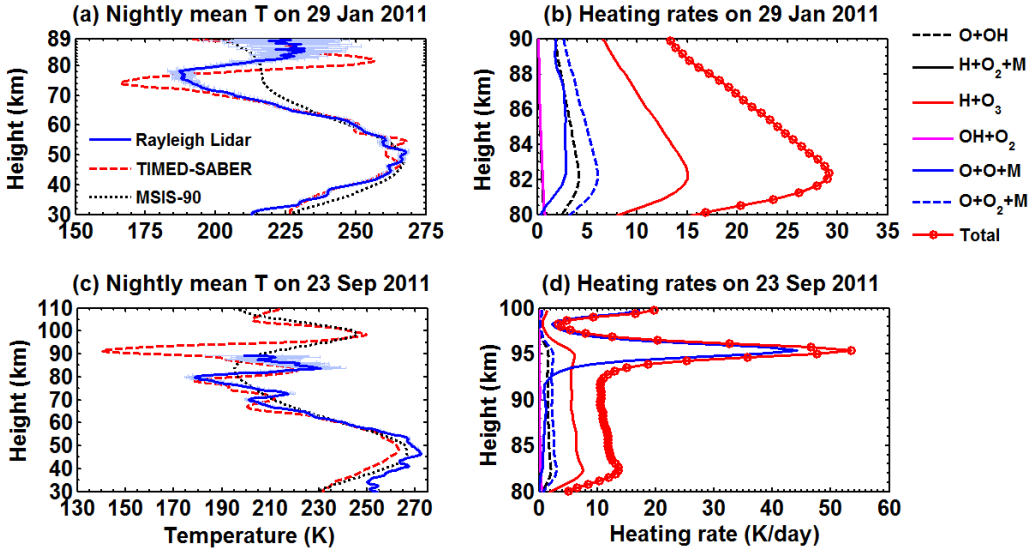


Figure 17*. (a,c) Height profiles of nightly mean temperature from Gadanki (13.5°N, 79.2°E) Rayleigh lidar, TIMED-SABER observations and MSIS-90 model and (b,d) heating rates due to various chemical reactions. (JGR 2014)*

- ✓ It is shown that the vertical wave number spectra of the Martian lower atmospheric temperature are often distinctly different due to dominance of radiative damping of atmospheric waves than that normally observed over the Earth's atmosphere.(ASL 2015)
- ✓ Various Lidar signal denoising methods were compared and empirical mode decomposition method was shown to be the best.(JoO 2015)
- ✓ Formation and maintenance of arare lower stratospheric cirrus were observed and possible link with Kelud eruption was shown. (Ann. Geophys. 2015)
- ✓ Sources for the gravity waves observed at airglow layers have been identified for the first time over the Indian region using reverse ray tracing technique (Fig. 18). A new empirical model for the neutral atmosphere from 0 to 100 km suitable for the tropical latitudes has been developed by combining several ground based and satellite measurements. (ACP 2015)

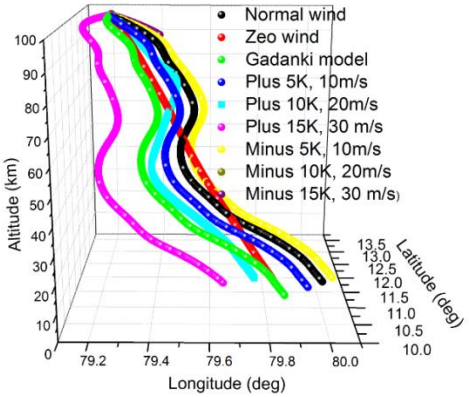


Figure 18. *Ray paths for gravity wave events observed over Gadanki on 17 March 2012. Ray paths obtained while considering different background wind conditions are also superimposed. (ACP 2015)*

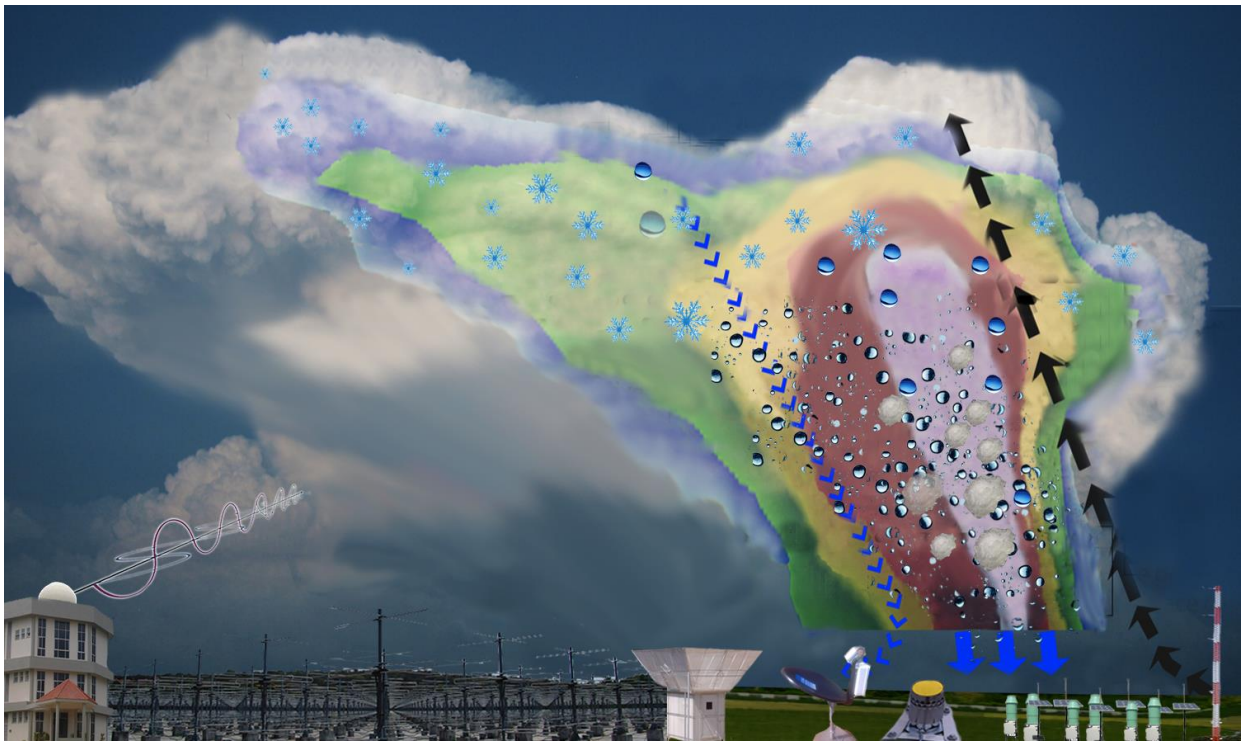
Way Forward (The Group will be addressing the following questions)

- What is the role of extra tropical forcing, ozone and water vapor in the UTLS region on STE processes?
- What are the processes involved in the formation and maintenance of cirrus clouds in the UTLS region?
- What is the impact of extratropical forcing on tropics and genesis of equatorial waves due to the lateral forcing?
- What are the factors influencing tropical cyclones and Asian monsoon system?
- Parameterization of convection generated gravity waves over the tropics
- How does the global distribution of chemical constituents change during the polar stratospheric warming events and its impact?
- How tides and waves vary along with latitude in the MST region?
- What are the dynamical factors control the coupling mechanism of the Earth's atmosphere from the surface to the ionosphere?
- What are the causative mechanisms responsible for the occurrence of mesospheric temperature inversions (MTI) observed in the lidar measurements?
- What is the role of tides on the tropical mesopause?
- How are atmospheric waves generated and dissipated in the Martian atmosphere?

Work Plan

- Realizing DIfferential Absorption Lidar (DIAL) for measuring Ozone concentrations for the study of troposphere-stratosphere exchange process.
- Establishment of wind profilers to study the behavior of extreme weather phenomena in the country.
- Building space based spectrometer/radiometer/instrumentation with wide range of atmospheric infrared bands to study the Earth's as well as other planetary atmospheres.
- Sodium airglow observations will be made simultaneously with the lidar observations of sodium concentration for studying sodium airglow intensity variations.

7.4. Clouds and Convective Systems Group (CCSG)



Group Members

Head: Dr. T NarayanaRao, M.Sc., M.Phil., Ph.D., Scientist/Engineer-SF

Scientific/Technical Staff

Dr. Anish Kumar M. Nair, M.Sc., Ph.D., Scientist/Engineer-SD
Mr. S Satheesh Kumar, M.Sc., (Ph.D.), Scientist/Engineer-SC
Mr. MohammedBasheer, B. Tech., Scientist/Engineer-SC

Research Fellows, PDFs, RAs

Mr. K Sunil Kumar, M.Sc., SRF

Photograph: Collage of instruments for understanding clouds and precipitating systems (Cloud image is taken from reef.atmos.colostate.edu).

Objectives

The research interests of CCSG are diverse and include studies on microphysics and dynamics of clouds, precipitation and other high impact weather systems, like severe thunderstorms and mesoscale convective systems (MCS), using a suite of in-situ and radar systems.

Understanding the small-scale processes occurring near the tropical and extratropical tropopause, boundary layer processes and their relation to the generation of convection, and monsoon dynamics.

Improving atmospheric probingtechniques and radar signal processing for better understanding the precipitation processes.

Major Research Accomplishments

Microphysics of precipitation: The raindrop size distribution (DSD) at the surface is the resultant of complex interplay between microphysical (evaporation, accretion, collision-coalescence, break-up, condensation, aggregation) and dynamical (drop sorting) processes. The debate concerning which process dominates in describing the surface DSD is still open. To advance the present understanding of the complex microphysics of rain, the variability of DSD between the rain types, cyclonic and non-cyclonic rain, and seasons, and also the variations within the season has been studied extensively by unravelling the causative mechanisms for the observed variations.

- ✓ Vertical profiles of DSD and gamma parameters retrieved using dual frequency technique employing measurements from VHF and UHF radars reveal a significant variation in the coefficients of the shape-slope relation of gamma parameters with height. The vertical variability of the relation has been ascribed to the microphysical processes (evaporation) occurring in the height region concerned in the present study. These results suggest that for accurate retrieval of drop size distribution from polarimetric measurements and also for studies on the microphysics of rain systems, the vertical variability of the relation needs to be accounted, in particular in an environment where the DSD variations are considerable. (GRL 2006)

- ✓ The rain rate-stratified DSD at Gadanki is found to be distinctly different in northeast monsoon (NEM) from that of in southwest monsoon (SWM) (Fig. 19). The low-level wind pattern, cloud effective radius and mass weighted mean diameter distributions in these seasons reveal that the cloud systems in SWM and NEM are continental and maritime in nature, respectively. However, the microphysical and dynamical processes related to evaporation and convection play an important role in modifying the DSD. These processes are found predominantly in SWM (because of high

temperature and intense convective activity) and are, primarily, responsible for the changes in DSD during their evolution. (JGR 2008; QJRMS 2009)

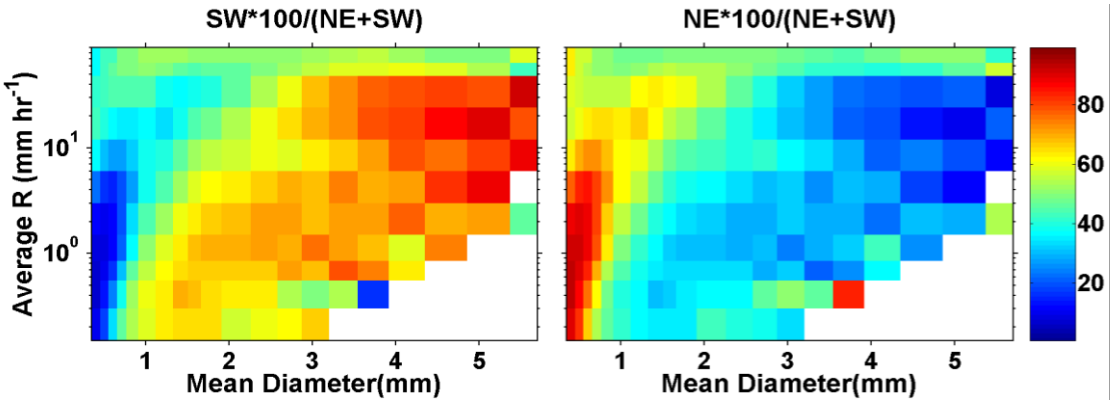


Figure 19.*Contribution of drops (in terms of %) in each season to the total number of drops at each drop diameter in different rain rate intervals. (JGR 2008)*

- ✓ An attempt has been made to effectively utilize the synergy of various approaches providing microphysical information of precipitation by combining the radar observations with isotopic analysis. Variation of stable oxygen isotope ratios ($\delta^{18}O$) within a mesoscale convective system (MCS) shows a 'V' type structure. It has been shown that the increase in stable isotopic abundance is due to the transport of hydrometeors, which are condensed at lower altitudes in the convective cloud, from convective region to trailing stratiform region. The condensates most likely retain their basic character acquired at the time of condensation and therefore, the height (or temperature) and the rain regimes of condensation are of paramount importance in determining $\delta^{18}O$. (GRL 2008; JAC 2012, 2015)

- ✓ Using a suite of instruments at NARL, the nature and origin of multipeakDSD have been studied, like the preferential stage and height at which the multipeakDSD occur in a MCS. The multipeakDSD is observed during the transition period from convective to stratiform rain.A statistical study later clearly shows that multipeakDSDs are not exceptional, rather observed at all altitudes, albeit with different occurrence percentages. The peaks in the DSD exist predominantly in drop diameter ranges of 0.45-0.65 and 0.9-1.3 mm in all types of rain, consistent with earlier numerical (attributed to the fragmentation of filaments, sheets and disks) and observational studies. (MWR 2009a, b)

- ✓ Seasonal differences in cyclonic-DSD are examined to understand the nature of cyclonic DSD and dominant microphysical processes. The big drops are almost absent in cyclonic DSD, while the small and medium-sized drops are larger in number than in non-cyclonic rain. Detailed analysis suggests that the observed seasonal differences in DSD are due to differences in microphysical processes occurring in the evolution of DSD during the drop descent. (JGR 2010)

Spatial and vertical distribution of clouds and precipitation: The clouds and precipitation during the monsoon season exhibit complex variability in both space and time over India, governed by a variety of processes related to synoptic systems, land-sea contrasts, orography, mid tropospheric cyclones and small-scale evening thunderstorms. Ground-based and space-borne radar measurements have been used extensively to study the characteristics of convective storms and distribution of different types of precipitation.

- ✓ The characteristics of up- and down-draft cores obtained by the MST radar indicate that considerable percentage (35%) of deep updraft cores show inclined structure with elevation angles as low as 0-20°. The variation of horizontal wind field with height and internal dynamics of MCS are thought to be responsible for this geometry.(MWR 2009c)

- ✓ It has been found that the TRMM algorithm either underestimates or overestimates the freezing level height (FLH) at latitudes > 20° N over India. The impact of misrepresentation of FLH alone affects the shallow rain occurrence and rain fraction by 3-8% over slopes of Himalayas, northern plains and northwest India. This situation could introduce large error in the correction of reflectivity for attenuation and in the retrieval of latent heat profiles. (JAMC 2013)

- ✓ Daily rainfall data obtained from 1025 rain gauges spread across the country over 51 years (1951–2001) are used to identify 26 (20) homogeneous rainfall zones in India. The tests that are performed toevaluate coherency of zones reveal that the zones are homogeneous not only at different temporal scalesbut also in terms of rain amount, rain frequency, and rain type. (JHM 2013)

- ✓ 15 years of TRMM PR measurements are used to study the spatial and seasonal variability of the vertical structure of precipitation over India and adjoining oceans. The dominant microphysical processes have been inferred from the height variation of contours of reflectivity. It has been found that evaporation (and as a result virga rain) and low level growth of raindrops are significant in northwest India and Arabian Sea, respectively. (JGR 2014)

- ✓ An extensive evaluation of five widely used multisatellite precipitation estimates reveals that allMPEs overestimate the rainfall over the dry regions (northwest and southeast India) and severely underestimate over mountainous regions (west coast and northeast India) (Fig.20). Higher occurrence of virga rain over the dry regions suggests that sub-cloud evaporation of rain could be the main reason for the observed overestimation of rain by MPEs. The severe underestimation of rain along the west coast is attributed to the predominant occurrence of shallow rain and underestimation of moderate to heavy rain by MPEs. (JGR 2015)

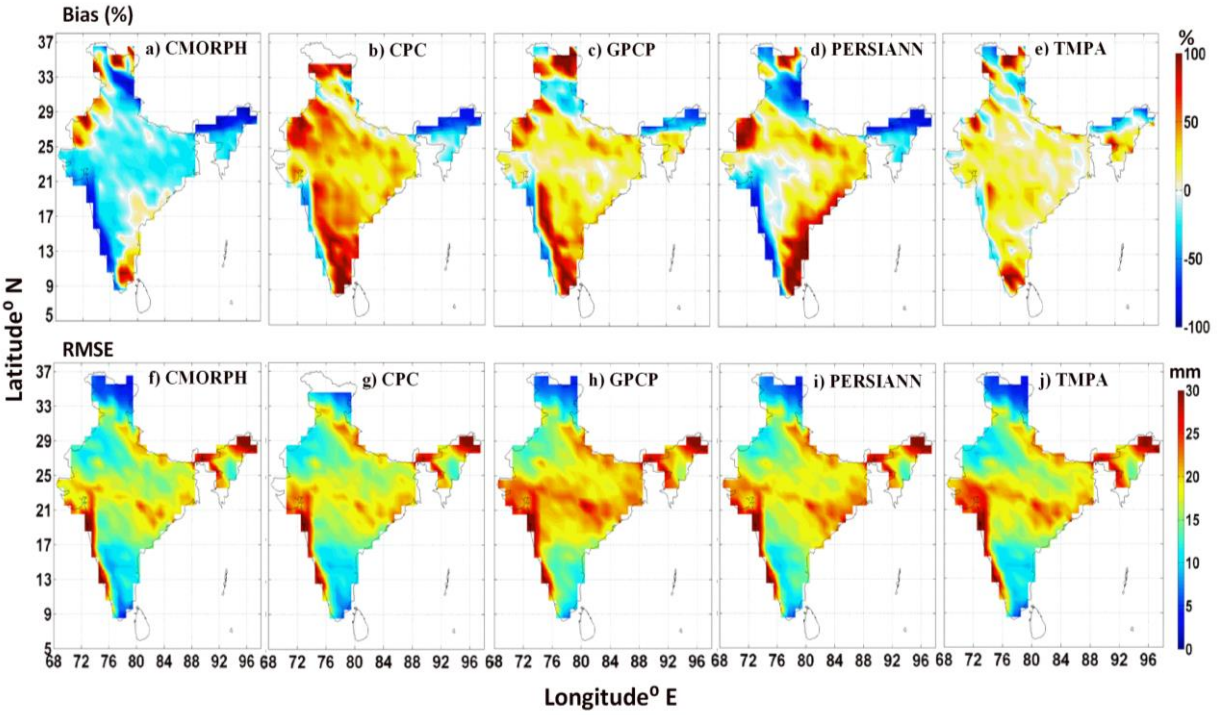


Figure 20.*Spatial distribution of seasonal rain bias by (a) CMORPH, (b) CPC, (c) GPCP, (d) PERSIANN and (e) TMPA, respectively.(f-J) same as (a-e), but for RMSE.(JGR 2015)*

Active and break spells of the monsoon: The intraseasonal variability of precipitation is regarded as one of the most important sources of weather variability in India. A series of studies have been carried out to understand the differences in the characteristics of surface forces, ABL, draft cores and precipitation between active and break spells of the monsoon.

- ✓ Contrasting convective cores during the wet and dry spells reveals two interesting facts, higher occurrence of shallow cores and the presence of bi-modal distribution in mean vertical velocity profile during the dry spell, illustrating that they are characteristic features of wet and dry spells. (MWR 2009d)

- ✓ The temperature and humidity variations from active to break spell are quite pronounced near the surface and in the atmospheric boundary layer (ABL), but not above the ABL. Interestingly, Convective Available Potential Energy (CAPE) is found to be higher during active spells than during break spells. A synthesis of all measurements reveals that favorable environmental conditions (high CAPE, humid atmosphere and weak stable layers) allow the convection to grow into a deep system in active spells. Strong stable layers, weak CAPE coupled with relatively less humidity above the ABL inhibits the growth of convective cloud during dry spells. (QJRMS 2012)

- ✓ The differences in ABL height, its evolution and the wind field between episodes are quite pronounced. Active spells not only have a shallower ABL but also their growth

is delayed by 1-4 hours when compared with that of in break spells. Abundant soil moisture during the active spells (a factor of two greater than during the break spells) reduces the buoyancy flux, as most of the radiation is converted into latent heat flux, and thereby not only limits the ABL height but also delays the start of ABL growth. (BLM 2014)

Exchange processes near the tropopause: Small-scale processes occurring near the tropopause play a crucial role in the transportation of constituents and the exchange between these two important layers. A detailed study has been carried out on the processes occurring near the tropopause (at both tropical and extratropical) as part of an international collaboration project with Swedish Institute of Space Physics (IRF), Kiruna.

- ✓ Characteristics of tropopause folds over Arctic latitudes have been studied using VHF radar measurements supplemented by balloon measurements. The signal-to-noise ratio (SNR) and vertical shear of horizontal wind clearly show the upper-air frontal zone (Fig.21). Utilizing the mean eddy diffusion coefficients and the mean ozone gradient values, the ozone fluxes across the tropopause and topside of the fold due to turbulence are estimated as 0.71 m s^{-1}ppbv and 0.32 m s^{-1}ppbv, respectively. Although the flux across the tropopause is more than that occurring near the fold, the exchange occurring through folds could be more significant to the tropospheric chemical budget. (JGR 2005)

- ✓ To resolve the ambiguity in the annual cycle of folds, 11 years of continuous measurements from ESRAD have been utilized. The climatology of tropopause folds exhibits a pronounced annual cycle with a large number of folds in winter and fewer in summer. The observed annual cycle is quite consistent with that obtained by the model data, but in contrast to the ozonesonde climatology. The differences in the climatologies are ascribed to the differences in the algorithms and the spatial variability of fold frequency. (JGR 2008)

- ✓ The seasonal mean vertical velocity (*w*) profiles at Gadankiand Kototabang show descending (ascending) motionbelow (above) 8–10 km in most of the seasons. The analysis suggests that thetransportation of air from near surface to the stratosphere is a two-step process: a rapid ascent from the surface to themiddle-upper troposphere in convective turrets, and a gentleascent into the stratosphere. Also, the convection requires toreach an altitude of 10 km, at least at the above locations, and thereafter the prevailing ascent transports the airinto the stratosphere. (GRL 2008)

- ✓ Coordinated measurements using MST radar and radiosonde during the passage of overshooting convective cores are utilized to quantify the mass flux across the tropopause and strength of the turbulence in up- and down-draft cores. The net mass flux isfrom the troposphereto stratosphere, in spite of the existence of

significantamount of downward flux. The average spectralwidth (and alsothe variation or standard deviation) in draft cores is foundto be ~4.5 times larger than that in fair-weather. The turbulencestrength in updraft cores is much higher than thatof in downdraft cores. (Ann. Geophys., 2010)

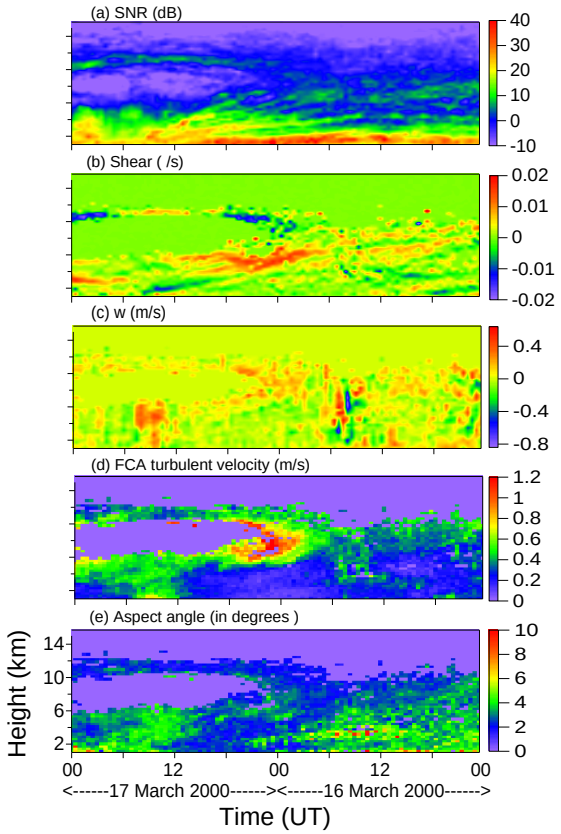


Figure 21. *Time-height cross-sections of ESRAD parameters during the passage of tropopause fold. (a) Signal-to-noise ratio (SNR), (b) wind shear, (c) vertical air velocity (d) FCA turbulent velocity, and (e) aspect angle. (JGR 2005)*

Improvements in the retrieval algorithms and signal processing techniques

- ✓ The UHF profiler measurements have been used to develop an objective algorithm to classify the tropical precipitating systems. The performance of this algorithm has been verified with the help of time-height maps of profiler moments and surface rainfall patterns. (JAOT 2008a, b)
- ✓ A comprehensive evaluation of SAPHIR-derived humidity profiles has been performed against a variety of reference-ground truths, like measurements from GPS radiosondes and ground-based microwave radiometer, reanalysis data sets and satellite retrievals. (Curr. Sci., 2013)
- ✓ A meso-network of rain gauges has been established to understand complex small-scale variability of rainfall (both in space and time). (HESS 2015)

- ✓ A novel approach has been proposed for the extraction of cloud motion vectors using airglow imager measurements. (AMT 2015)

Way Forward (The Group will be addressing the following questions)

- ➢ Does the complex topography play any role in either enhancing or suppressing the rainfall over southeast peninsular India?
- ➢ Which physical process/mechanism explains the observed late-mid night peak in rainfall at Gadanki and the surrounding region during the SWM?
- ➢ How accurate is IRIS concept in explaining the physics of 32° C limit of SST on cloud development?
- ➢ What is the impact of cloud radiative forcing on the diurnal variation of the surface heating and atmospheric dynamics?
- ➢ Is there more than one mechanism which controls the pool of inhibited cloudiness?
- ➢ How can we improve quantitative precipitation estimates over India?
- ➢ What is the nature and source of post sunset turbulence in ABL?
- ➢ How does the ABL respond to mesoscale circulations, like sea-breezes and valley winds?

Work Plan

- ➢ An X-band polarimetric scanning radar is being developed at NARL in technical collaboration with ISTRAC, Bangalore to address several issues listed above. In addition, it provides unique information on rainfall that will be useful to understand microphysics and small-scale variability of precipitation and also to evaluate satellite-precipitation estimates.
- ➢ Balloon-borne experiments are being planned in the next 2-3 years to understand the turbulence structure in the troposphere and lower stratosphere and post sunset turbulence in the ABL. A hot-wire anemometer that can provide wind fluctuations at 100 KHz resolution is being procured to obtain the turbulence structure.
- ➢ Space-borne precipitation radar orbiting at low inclination will resolve many of the issues related to the precipitation, for instance, vertical structure, latent heat profiling and improving quantitative precipitation estimates. NARL stressed the need for the development of space-borne precipitation radar in different brain storming meetings organized by ISRO/ADCOS for future space-borne systems and would like to play an active role in the development of such a space-borne radar.

7.5 Aerosol Radiation and Trace-gases Group

Group Members

Head: Dr. Harish Gadhavi, PhD, Scientist/Engineer-SE

Scientific/Technical Staff:

Prof. A Jayaraman, M.Sc., Ph.D., OS
Dr. V Ravi Kiran, MSc, Ph D, Scientist/Engineer-SD
Dr. Chaithanya Jain, MSc,Ph D, Scientist/Engineer-SD
Mr. TusharWankhede, BTech, Scientist/Engineer-SC

Research Fellows, PDFs, RAs
Dr. K Renuka, PhD, PDF
Mr. Amit Kumar Pandit, MSc, SRF

Photograph: A view of the Climate Observatory.

Objectives

Investigating the role of aerosols, radiation and trace gases on regional and global climate.

Improving the understanding of role of meteorology in controlling the aerosol surface concentrations, vertical profile and chemistry.

To better understand the aerosol-cloud interaction and its impact on global climate.

Major Research Accomplishments

- ✓ A comprehensive climate observatory consisting of various state-of-the-art instruments for measuring climate essential variables like aerosols and trace gases to generate long-term data sets has been established for climate change studies.
- ✓ The data collected from this observatory have brought in focus the air quality problem involving black carbon etc., in rural regions of India. (Ann. Geophys., 2010)
- ✓ An algorithm has been developed to separate contribution of soot particles in aerosol absorption coefficient based on sources of their origin viz. fossil fuel vis-a-vis non-fossil fuel. (Ann. Geophys., 2010)
- ✓ Aerosol optical depth measured from the climate observatory is found useful to identify a reason for underestimation of AOD by MODIS satellite over South India, caused due to the use of less absorbing type aerosol model in the retrieval algorithm. (AMT 2014)
- ✓ Spatial homogeneity of aerosol optical depth over South India has been estimated using satellite data. From the study it has been found that aerosol variability has two distinct features over South India. (JASTP 2013)
- ✓ Using satellite data, it has been discovered that the net cloud radiative forcing is unbalanced over Bay of Bengal with large negative value during summer monsoon season. It is found that the vertical profile of cloud microphysical properties plays a significant role. (Clim. Dynamics, 2015)
- ✓ Long-term trends in NO_2 and O_3 concentration are found to be highly varying geographically in South India. NO_2 is found to be increasing over cities like Chennai, Vizag, Bellary, etc. and over the river basins where intense agriculture is practiced, but it has decreasing trend over large region in the western parts of South India. (Fig. 22; JAC 2014)

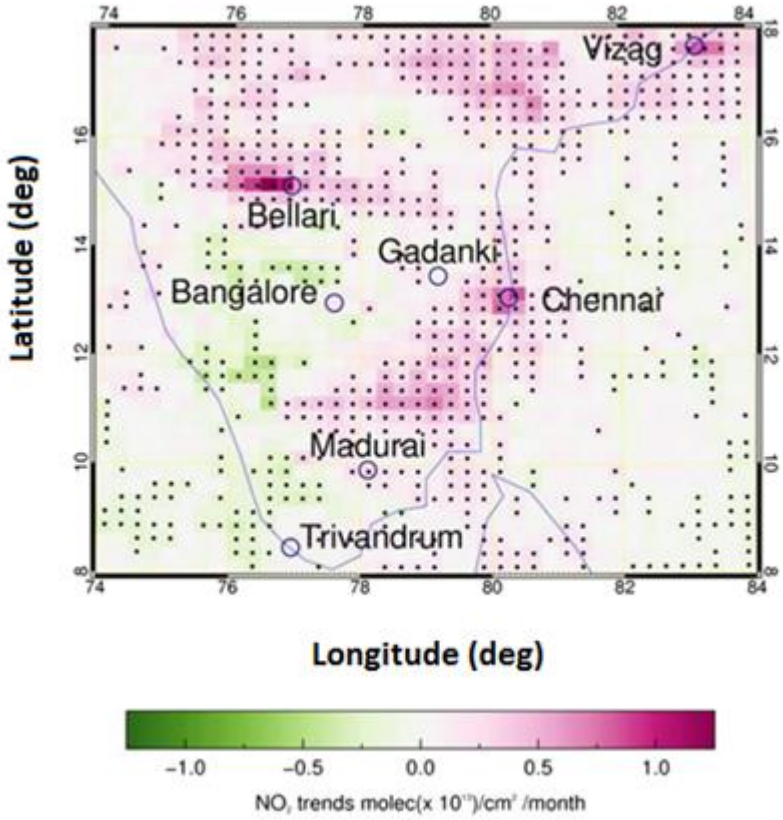


Figure 22. *Long-term trends in tropospheric NO_2 concentration estimated using OMI and GOME satellites for the period from 1996 to 2011. Grid-boxes with dot represent the statistically significant trend. (JAC 2014)*

- ✓ Ultra-fine size range aerosol observations are being carried out. New particle formation (NPF) events are observed very rarely (6% out of 79 observation days) at our site. This frequency is much lower than at most other studied locations around the world during May to July. Such a rare occurrence of NPF at our site could be explained by the combination of a weak gas-phase oxidation chemistry due to diminished solar radiation on persistently cloudy days as a result of the onset of the monsoon in early June and possibly also lower precursor gaseous concentrations, whereas other important environmental factors, such as condensation sink, relative humidity, temperature, wind speed and direction, and mixing layer were similar on both the NPF and non-NPF event days. (AE 2014)

- ✓ Long-term analysis of cirrus cloud properties have confirmed the increase in altitude of occurrence and increase in fraction of sub-visible cirrus cloud predicted by models in warming world scenario. (Fig. 23; ACPD 2015, JASTP 2014)

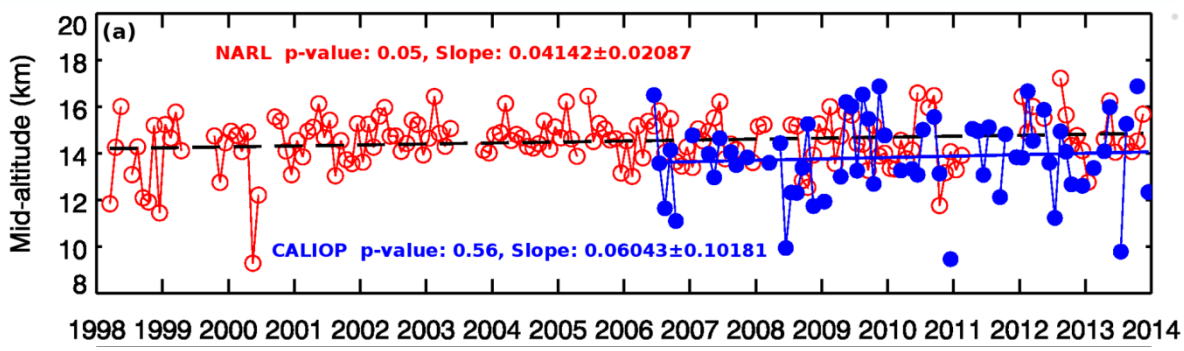


Figure 23. *Long-term trends in mid-cloud altitude of sub-visible cirrus clouds estimated using ground-based LIDAR at NARL and space-borne LIDAR on-board CALIPSO. Statistically significant increasing trend is found in the mid-cloud altitude of cirrus clouds. The finding is significant since the increase in cirrus cloud altitude is predicted under warming world scenario. (ACPD 2015)*

- ✓ The latest black carbon emission inventories over India are found to be underestimating the emission flux by a factor of 1.5 to 2.5 in a evaluation study conducted using data from the climate observatory. This is due to underestimation of emissions from agriculture waste burning and forest fires. (ACP 2015)
- ✓ Study on transport pathways suggests that more than 40% of black carbon load over rural regions of South India is contributed by air mass transport from North India. (Fig. 24; ACP 2015)

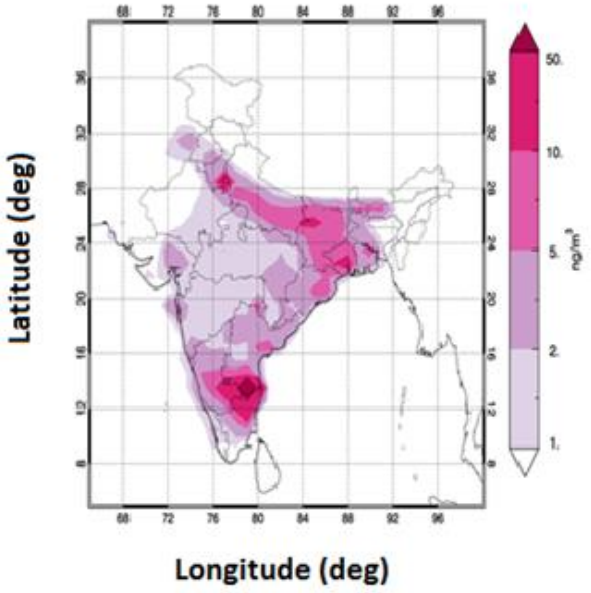


Figure 24*. Annual mean source contribution map of black carbon load at Gadanki (NARL). More than 40% of black carbon load is by transport from North India. The contribution of North India in BC concentration at Gadanki is as high as 60% during winter. (ACP 2015)*

Way Forward (The group will be addressing the following questions)

ARTG group's ambition is to study composition of the atmosphere in particularly minor constituents.

- What are the long-term trends in aerosol properties and trace-gases concentration and their implications to global and regional climate?
- What is the role of aerosol in altering the cloud microphysical properties and its vertical distribution over India and adjoining oceans?
- What are the vertical distributions of trace-gases and do chemical transport models capture convective and boundary layer mixing processes correctly?
- What are the dry deposition and wet deposition rates for aerosols in different climate regimes specific to India?
- What is the mixing state (external vs. internal) of aerosols in background rural atmosphere?
- What role do biogenic emissions and biomass burning play in ozone formation in rural environment?
- What are the important sources and sinks of methane over India?
- What is the hydroxyl radical concentration in tropical climate and quantification of its role in controlling greenhouse and trace gases concentration?

Work Plan

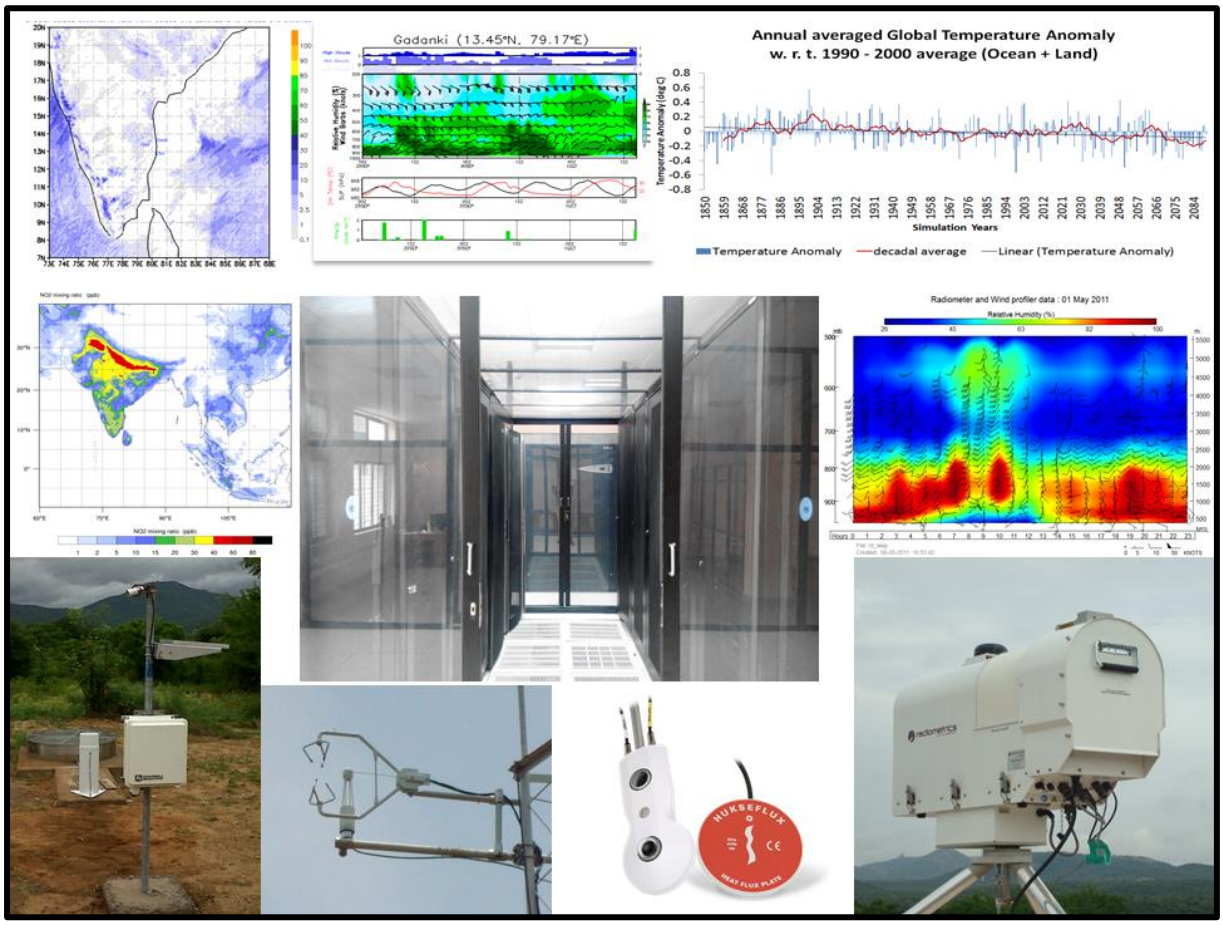
- Existing set of instruments will be replaced with instruments with better sensitivity and accuracy in a phased manner to continue monitoring of aerosol and trace-gases properties over a long period of time.
- The existing LIDAR (Light Detection and Ranging) system will be replaced with a dual polarization multi wavelength day-time capable LIDAR system.

- Monitoring of methane, volatile organic compounds and organic aerosols will be included as a part of regular measurements from the climate observatory.

- An analyzer to measure hydroxyl radical concentration will be developed in-house.

- A full-fledged atmospheric chemistry laboratory will be established with facility for analytical chemistry, smog chambers and cloud chambers.

7.6 Weather and Climate Research Group



Group Members

Head: Dr. Amit P Kesarkar, M. Sc. Ph.D., Scientist /Engineer SE

Scientific/Techical Staff

Ms.Jyoti N Bhate, M.Sc.,MCA,(Ph.D) Scientist /Engineer-SD
Dr. Vikas Singh, M.Sc., M.Tech., Ph.D., Scientist /Engineer-SD
Dr. V Yesubabu, M.Sc., Ph.D., Scientist /Engineer-SD
Mr. Harish Varma, B.Tech.,Scientist/Engineer-SC

Students, PDFs, RAs

Mr. U Umakanth, M.Sc.,SRF
Ms.Rajasree V P M, M.Sc., SRF

Photograph: Simulations of Weather, Environment and Climate, HPC system and weather observatory

Objectives

Research on weather, environment and climate modelling to simulate their multiscale evolution over the Indian region.

Development of tailored atmospheric models for weather, environment and climate prediction for the Indian region.

Development of scientific algorithms like physical parameterization schemes relevant for the Indian region.

Prepare real time daily weather forecasts using the WRF mesoscale model and participates in weather forecast campaigns during ISRO rocket launch operations.

Major Research Accomplishments

- ✓ The intra-seasonal variation of daily rainfall distribution over India associated with various phases of eastward propagating MJO life cycle has been examined using high resolution daily gridded rainfall data of India Meteorological Department (IMD) and Wheeler–Hendon MJO indices. Onset day of majority of the break events 83% of the total break events observed to be associated with the Phases 7, 8, 1 and 2 with maximum during Phase 1 (Fig.25). Similarly onset day of 84% break events of the duration of greater than 6 days were observed to be associated with these four Phases with maximum during Phase 1. All of the four long duration break events (≥10 days) observed to be associated with the Phases 7 and 8. (Clim. Dynamics, 2009)

- ✓ Temperature structure parameter has been calculated using Doppler SODAR to understand turbulence over Gadanki and characterize its behavior during monsoon season. It is demonstrated that the impact of mechanical turbulence on scaling parameter needs to be incorporated in the planetary boundary layer parameterization. (JESS 2009)

- ✓ A criterion has been defined for the identification of active and break spells of the Indian summer monsoon based on high resolution daily gridded rainfall dataset over India for the period 1951–2007. (JESS 2010)

- ✓ A severe thunderstorm observed over Gadanki on 21 May 2008 has been simulated using high spatial resolution (2 km) to examine ability of WRF model to simulate the main features of the thunderstorm and its sensitivity to different microphysical schemes viz. Thompson, WSM6, Lin and Morrison. All simulations correctly suggested passage of two convective cores over Gadanki, as observed by the MST and Doppler Weather radars (Fig. 26). The overall conclusions underlined a need for generation of multi-

observation platform of atmospheric dynamical-thermodynamical variables along with observations of aerosol, cloud properties and land heterogeneities to better parameterize the convective and microphysical processes. (Ann. Geophys.2010)

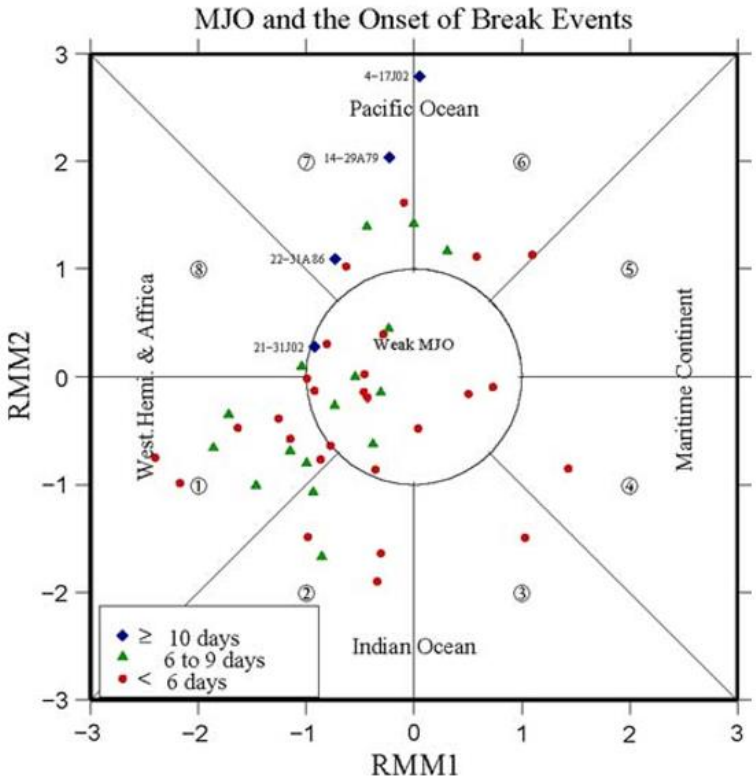


Figure 25.*The Phase–space diagram depicting MJO indices for the first day of the 47 break events occurred during the period 1974–2008 excluding 1978. Different markers have been used in the Phase diagram to distinguish between break events of duration of <6 days, 6–9 days and ≥10 days.The encircled numbers inside eight sectors of the diagram represent eight phases of the MJO in the diagram. In addition, events of duration ≥10 days have been shown with labels indicating their duration. For example, the label 14-29A79 means the break event of duration 14–29, August, 1979. (Clim. Dynamics, 2009)*

- ✓ The inland penetration of sea breeze has been studied using SODAR data at Gadanki and it is found that sea breeze penetrates in land during late afternoon in the height range 0.2 – 0.6 km during 14-20 local time. (AR 2012)

- ✓ A perfect prognosis prediction model has been developed to predict the probability of lightning and probable time of its occurrence over the south-east Indian region.(JESS 2012)

- ✓ The Cloudsat data (2007-2010) has been analyzed and the mean vertical structure and distribution of cloud properties has been studied during the Indian Summer Monsoon Season. (Clim.Dynamics, 2012)

✓ Indian summer monsoon circulation and rainfall have been simulated using regional model WRF with observed sea surface temperatures as boundary conditions compared with the TRMM rainfall observations. The results show that positive bias in the low level vorticity contributed to the wet bias of rainfall over the Indian region. (IJRSP 2012)

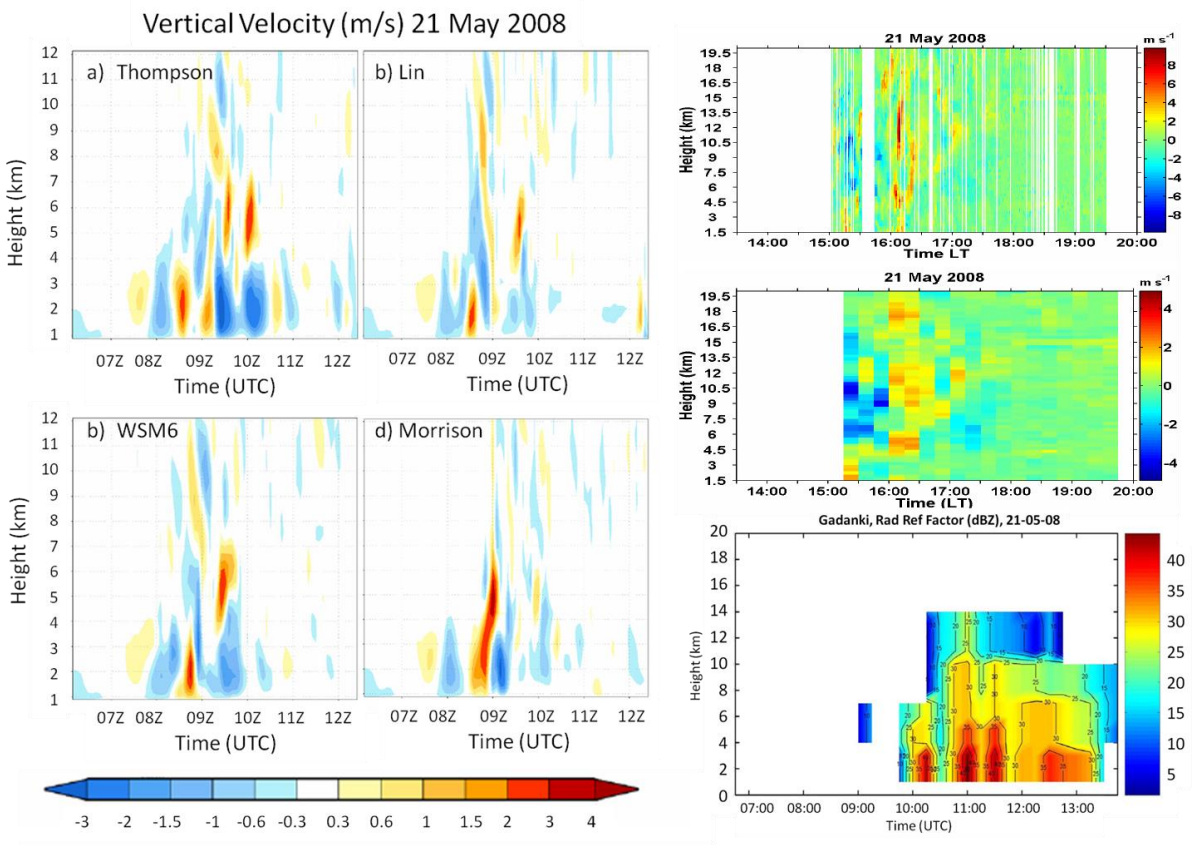

Vertical Velocity (m/s) 21 May 2008
a) Thompson
b) Lin
b) WSM6
d) Morrison
Height (km)
Time (UTC)
07Z 08Z 09Z 10Z 11Z 12Z
-3 -2 -1.5 -1 -0.6 -0.3 0.3 0.6 1 1.5 2 3 4
21 May 2008
Time LT
Time (LT)
Gadanki, Rad Ref Factor (dBZ), 21-05-08
07:00 08:00 09:00 10:00 11:00 12:00 13:00

Figure 26.*WRF model simulated vertical velocity (ms^{-1}) over Gadanki with (a) Thompson, (b) Lin, (c) WSM6, and (d) Morrison on 21 May 2008. Positive (negative) values refer to updraft (downdraft. (Ann. Geophys., 2010)*

✓ Diurnal, intra-seasonal and multi-decadal statistical relationships have been established between ENSO and the North East Monsoon Region over India using four state of art coupled climate models. The results indicated that during recent decade the statistical relation between ENSO and NE monsoon is significantly weakened due to enhanced rainfall activity during La-Nina years and suppressed rainfall activity during El-Nino years. (Metorol. Appl., 2012)

✓ A strategy has been devised for nowcasting thunderstorms using microwave radiometer profiler data. The super epoch analysis shows that there are sharp gradients in eight thermodynamic parameters at least 3 hours prior to the storm occurrence (Fig. 25). (JGR 2013)

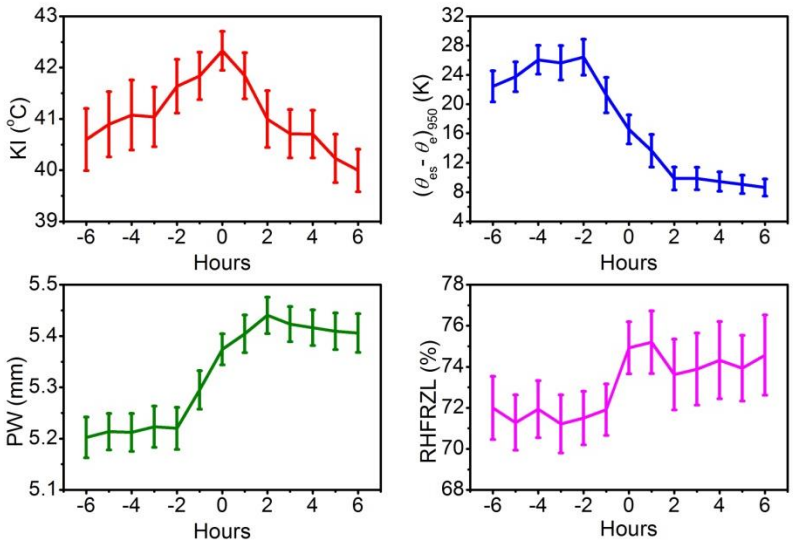


Figure 27.*Composite picture of various instability indices from super-epoch analysis (JGR, 2013)*

- ✓ A high resolution (0.5°, hourly) land surface dataset has been developed over the south Asian monsoon region using HRLDAS and daily forcing parameters viz. TRMM rainfall, MODIS land use data and vegetation fraction. This data set is being used for initialization of static parameters in regional models. (Curr. Sci., 2013)

- ✓ A new objective criterion has been proposed for identifying breaks in Indian monsoon rainfall using grid point threshold to account intra-seasonal spatial variability of rainfall over the Indian region. (ASL 2015)

- ✓ An Adaptive Neuro-fuzzy Inference System (ANFIS) has been developed to retrieve profiles of temperature and humidity up to about 10 km over the tropical station Gadanki using microwave brightness temperatures observed by radiometer (Fig. 28).The comparison of bias, mean absolute error (MAE), RMSE and symmetric mean absolute percentage error (SMAPE) of retrieved temperature and relative humidity (RH) profiles using ANN and ANFIS also indicated that profiles retrieved using ANFIS(RD + NRD) are significantly better compared to the ANN technique.(AMT 2015)

- ✓ 251 years of climate have been simulated from 1851 to 2100 to assess the natural variabilities using Community Earth System Model. The impact of climate change on Indian monsoon region has been studied by downscaling the climate predictions using regional climate model. (Clim. Dynamics, 2015 in press)

- ✓ A high performance computing system (28TF) has been established for weather and climate modelling studies.

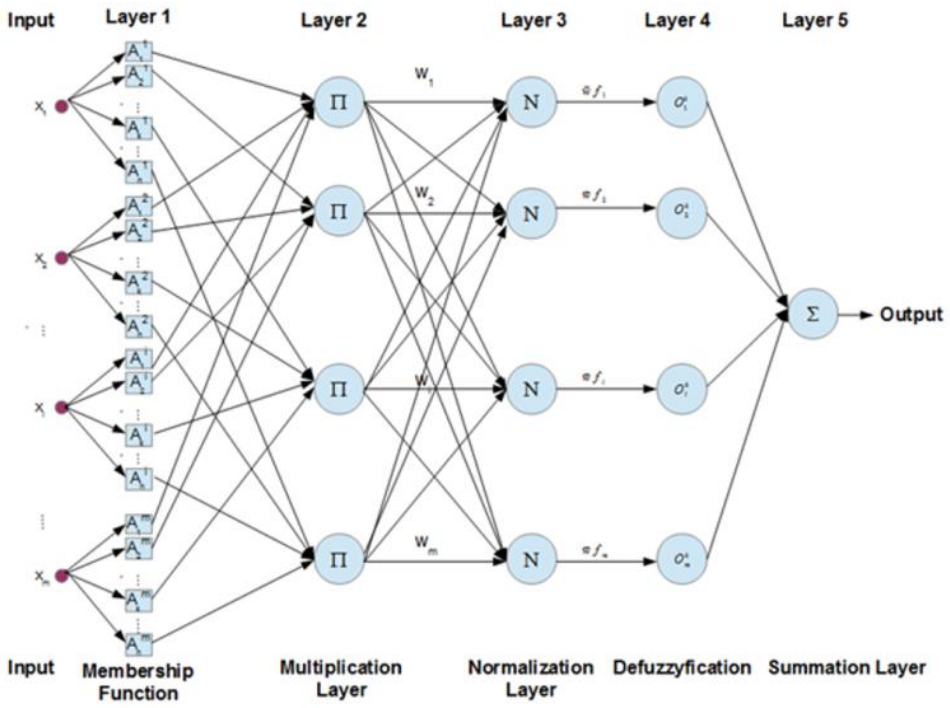


Figure 28.*An architecture of Sugeno type ANFIS developed for retrieval of temperature and humidity using microwave radiometer where m=10, n=2, i=1,2 and k=1,2, .., 10.(AMT 2015)*

- ✓ High resolution weather observatory has been established using Microwave Radiometer, Eddy Covariance Surface Flux Tower, Net Radiometer, Soil moisture, soil temperature and soil moisture flux measurement sensors,IR Thermometer and pan evaporimeter to study the land surface interaction with planetary boundary layer.

- ✓ High resolution real time weather forecast system (2km) with 4DVAR data assimilation has been developed to provide daily forecast. These forecasts demonstrate excellent correlations with in situ observations over SHAR and Gadanki.

- ✓ Weather forecast has been provided for 18 PSLV and 4 GSLVISRO Satellite Launch missions since 2009. In addition to this, weather forecast to support NARL campaigns (BATAL-1, PMC, BATAL-2) has also been provided.

- ✓ Various thunderstorms, mesoscale convective systems and tropical cyclones have been simulated using advanced assimilation techniques (3DVAR/4DVAR/EnKF) and mesoscale models at very high spatial and temporal resolution to understand the physical mechanisms of convection genesis and evolution on different spatial / temporal scales.

- ✓ Recently air quality modeling system has been established to understand impact of different physical and chemical mechanisms associated with trace gases and aerosols.

Way Forward (The group will be addressing the following questions)

Physical Parameterization and Advanced Model Developments

- How to ensure the stability of fundamental equation of motion on adaptive grid with different spatial and temporal resolutions with different integration scales?
- How to discretize the model equations adaptively to generate optimal mesh for multiscale models?
- How to partition the complex computational load on different number of processors for efficient integration of models?
- How to make improvements in the adaptation of fundamental equations of motions and physics equations represented in weather, environment and climate models?

Mesoscale Modelling

- What are the different mechanisms of convection initiation and evolution over tropical Indian region? What are the effects of these mechanisms on diurnal cycle of rainfall? How mesoscale models captures the diurnal cycle of rainfall over various seasons?
- How the prediction of severe convective events like heavy rainfall, lightning, heat wave can be improved in mesoscale models?
- How land surface parameters affect the evolution of boundary layer during convection? What is their role in triggering convection over tropical region?
- What is the skill of mesoscale models in simulating the convectively generated gravity waves and their propagation to upper altitudes?

Air Quality Modelling

- How to improve the air quality simulations and predictions over the Indian region through parameterization and data assimilation and their impact on agriculture, health and climate?
- What are the processes that lead to higher level of pollution, whether they are dominated by emissions or meteorology? This will help us to understand the effect of surface and PBL parameterization on the atmospheric pollutants, role of anthropogenic and natural emissions (eg. biomass burning, dust, vehicular emissions etc.) on Indian air quality.
- What are the feedback interactions between composition, meteorology and climate important for air quality in India?
- What will be the future levels of pollution in a changing climate scenario?

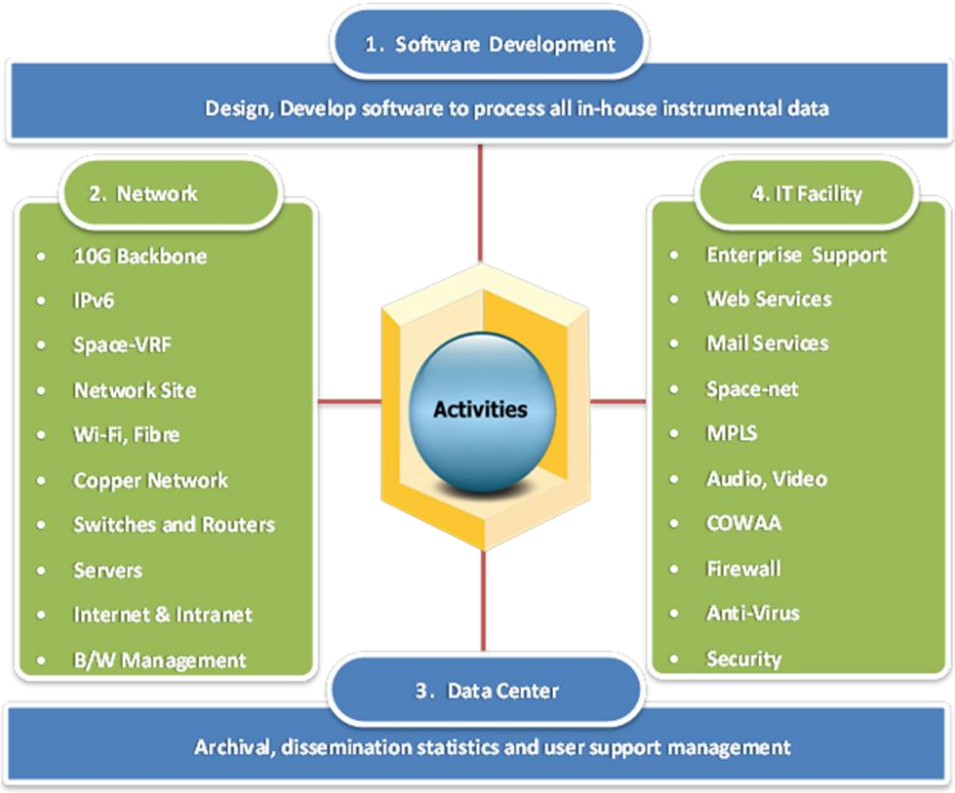
Data Assimilation

- What is the impact of assimilation of satellite radiance versus conventional data for the simulation of thunderstorms, mesoscale convective complex (MCC) activity over south-east coast of India?
- What is the role of satellite radiances data assimilation and static and flow-dependent background model errors for the prediction tropical cyclones over Bay of Bengal?
- What is the impact of coupled ocean–atmosphere prediction system on simulations of tropical cyclone over Indian region?

Work Plan

- Enhance the activities of WCRG to cater to advanced numeric and computational problems applicable for environment, weather and climate modeling by development of scientific algorithms / model parameterizations especially for land surface, planetary boundary layer, large eddy simulations, radiation, cloud microphysical and cumulus development processes in the atmosphere.
- Development of Coupled Polyhedron Multiscale Prediction Model for short, medium, long range, climate and centennial scale predictions. Validate it for multiscale atmospheric circulation, processes and atmospheric phenomena like tropical cyclones, convections, Indian monsoons and western disturbances.
- Evaluation of available earth system models, global and regional scale models for weather and climate prediction over short to centennial scale predictions to understand their applicability for environment, weather and climate of Indian region.
- Evaluation / development of advanced algorithms for atmospheric, oceanic and coupled data assimilation and study of impact of data assimilation of different in-situ and satellite on their predictions over different scales.
- Development / evaluation of chemical transport/air quality models/ scientific algorithms for improvement of air quality predictions over Indian region. Development of high resolution chemical emission inventory and high resolution atmospheric air quality modeling system.
- Establishment of 500 TFlops High Performance Computing System for weather and climate research with 2PB storage system.
- Establishment of advanced high resolution weather observatory (portable) required for physical parameterizations in atmospheric models.

7.7 Computers and Data Management Group



Group Members

Head: Manas Ranjan Padhy, M.Tech, Scientist/Engineer-SE

Scientific/Technical Staff

Mr. P Munirajulu, B.Tech, Scientist/Engineer–SC

Mr. T Krishna Sumanth, MCA, Sr. Scientific Assistant-A

Photograph: A picture of the Data Center and the activities of the group.

Objectives

To establish a data center as per international standards and manage the data archival and data dissemination processes.

To create, establish and manage network infrastructure and all other IT operational facilities.

To design and develop industry standard web based and desktop software application packages for in-house use and distribution.

Major Accomplishments

- ✓ **NARL Data Center**
  - Planning, Implementation and Management
- ✓ **NARL Data Centre Portal**
  - Software for effective data utilization
- ✓ **Duct Climatology Software**
  - Strategic application used by Indian NAVY
- ✓ **Rainfall Information Software**
  - For Megha - Tropiques ground validation
- ✓ **Wind-Information Portal**
  - used for rocket launches
- ✓ **Data Analysis Software**
  - MST Radar and Wind Profilers
- ✓ **NARL Principal Website and it's Hindi Version**
- ✓ **Information Websites**
  - Paperless recruitment portal
  - e-attendance portal
  - e-noticeboard portal
  - Experimental facility management portal
  - Online Examination portal
- ✓ The **Radar Controller Firmware** for MST Radar
- ✓ The **Distributed Radar Controller Firmware** for MST Radar
- ✓ The **Fiber optics control System** for Radars
- ✓ **Firewall, Web-Servers and E-Mail Servers**
  - Establish and Management
- ✓ **Network Infrastructure**
  - Establishment, Augmentation and Management
- ✓ **Computer System Administration** and **Database Administration**
- ✓ **Software Quality Assurance and IT Service Quality Assurance**
  - Enterprise Docket management System
  - COWAA, Hardware services, Software services
  - Network and other IT facilities

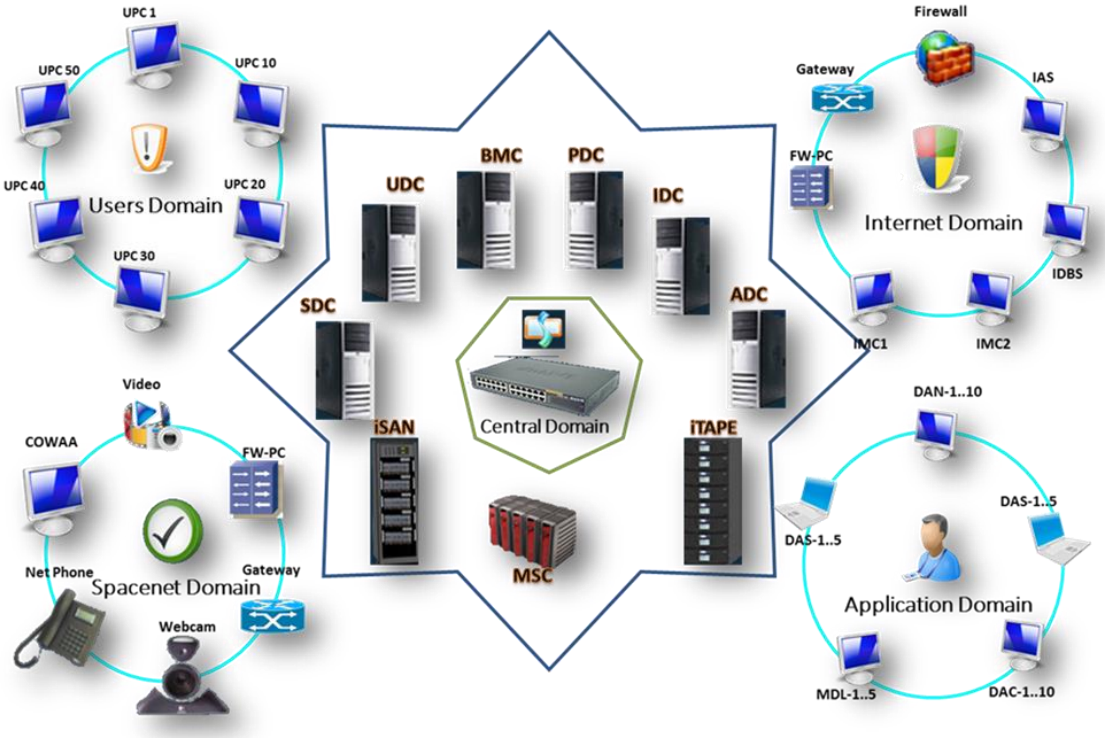


Figure 29. *Implementation schematic of Data center*

- ✓ **Establishment and Configuration of datacenter**
  - It has 5 Domains viz., Central, Users, Application, Internet & Space-net
- ✓ **Central Domain**
  - It comprises of 250TB Storage system**,** configured in 3-Tier D2D2T architecture with Raid5, LTO4
- ✓ **Users Domain**
  - It facilitates usage of data for scientific purposes among users
- ✓ **Application Domain**
  - It contains all the required policies regarding Data Analysis, Data Archival, Data Assimilation, Data Modeling and Data Dissemination.
- ✓ **Internet Domain**
  - It manages data maintained by IDC of the central domain. Internet Database Server (IDB) maintains database for internet user access and other downloading / uploading related issues.
- ✓ **Spacenet Domain**
  - It routes to ISRO server. SDC further caters the policies of separation for the INET domain. The video conference setup is facilitated to have proper audio-video link to the headquarters and other DOS centers.
- ✓ **Information Life Cycle Management (ILM)**
  - It is programmed using Bru/Dax utility, used for scheduling Life of data.

NARL Data Center Portal –Software for effective data utilization

Figure 30. *A glimpse of Data center software*

Plan, Design, Development & Integration of a web based Data Portal having the following modules

- ✓ **Data Pre-Processing Module**
  - Facilitate users to procedurally Clean, Integrate, Select and Transform data
- ✓ **Data Upload Module**
  - Facilitate users to Buffer, View and Registering files and folders
- ✓ **Meta-data Search Module**
  - Facilitate users to search based on Atmospheric condition, Filename, Time
- ✓ **Data Analysis & Quality tagging Module**
  - Process and generate L2 & L3 data, tag Data quality information
- ✓ **Data View & Download Module**
  - Facilitates Data Visualization at Cycle to Frame level
- ✓ **Management Modules**
  - User Management, Type Management, Complaint & Rights Management
- ✓ **20GB metadata** for **Search Performance Optimization**
  - It handles 50TB of data from 21 different instruments with file size from KB to GB with at varying Transparencies
- ✓ **Database Design**
  - It includesSQL performance Tuning, Normalization, Relationships, Views, Keys, Stored Procedures, UDF, Cursors, Triggers and Indices

Duct Climatology Software

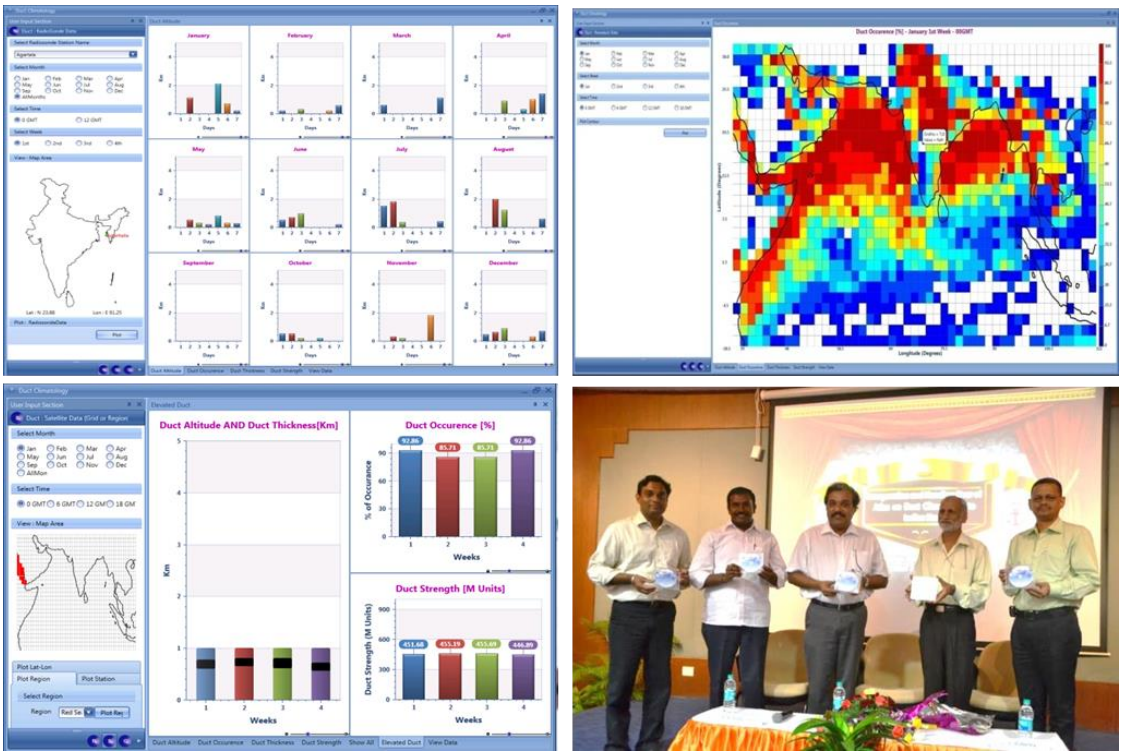


Figure 31. *Software, a Strategic importance to Indian NAVY.*

Duct climatology software has been developed for the Indian Navy. Theworkinvolvesdevelopmentof application software for Desktop and Web to bring out the Climatology, over the Indian region. The salient features are as below:

- ✓ Duct climatology includes Duct Occurrence, Duct Altitude, Duct Thickness and % of Duct Occurrence
- ✓ The total data resides in SQL server Data base and the project has a typical client server architecture optimized for quick access and plotting
- ✓ Software uses 7yrs of Radiosonde data from 34 stations, 12yrs of Satellite data and 12yrs of model data
- ✓ Atlas is organized in 1372 grids at 2.5° resolution, has 10million records sizing 11GB, derived from 200GB
- ✓ Developed using WPF& Silverlight with Incremental SDLC which output text, CSV & 2D images

Wind Information Portal

Extensively used during Rocket Launches at SDSC-SHAR

- ✓ Development of Wind Information Portal to support launch. The auto refreshing GUI facilitates onscreen current wind information with tooltip with inter comparisons.
- ✓ The portal developed on a 3-tier architecture provides wind data download to use in other launch processes

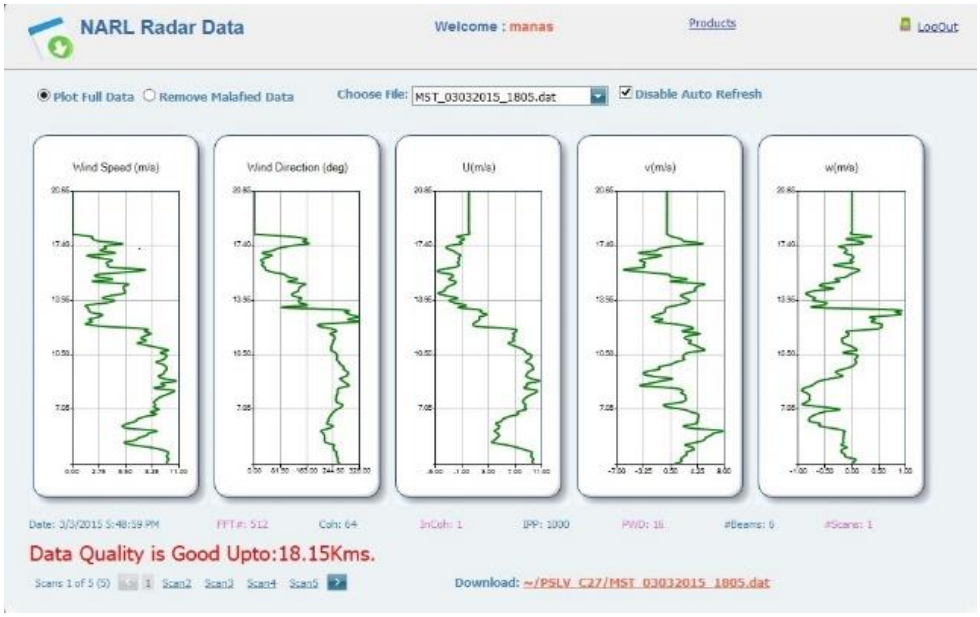


Figure 32. *Web based Software to access MST Radar Wind information during launch programs.*

Way Forward (The group will be involved in the following activities)

- **Augmentation of Storage Facility**

  Over the past few years it is observed that there is a consistent increase in the volume of data, archived in the data center. The stake holders of the instruments are still holding lots of data which is scheduled to be archived into the data center at later stage. Further, the imaging radar under implementation will generate enormous amount of data. To handle such a huge inflow of data, CDMG requires augmentingits storage spaceto at least 1 petabyte using latest SSDs technology.

- **Software Development and Data Analysis**

  NARL has several Radars and other co-located experimental facilities. In order to standardize the data processing and data format it is proposed to design, develop and validate state of the art software and will be made available to the users.

- **Data Mining and Short Term Predictability**

  It is proposed to develop soft computational approaches for data mining, as the data center hosts large amount of scientific data collected over a period of two decades. For which a very good cluster with a capability of 25 TFLOPS and necessary software for data mining will be realized.

- **Creation of Computing Facility for Application Development**

  Processing of voluminous data from several receivers of imaging radar is estimated to be complex and cumbersome. The above cluster projected for data mining will be multipurpose in nature, while serving both Mining and Imaging operations.

7.8 LIDAR Project

Group Members

Head: Dr. Y Bhavani Kumar, M Sc., Ph.D., Scientist/Engineer-SF

Scientist/Technical Staff
Mr. S Jaswanth, B.Tech, Scientist/Engineer-SC

Student
Mr. R Vishnu, M.Sc, SRF

Photograph: The lidar instruments such as BLL, LAMP, DPL, ERL and CBL, developed in-house.

Objectives

Establishment of Indian LIDAR network using Indigenous boundary layer lidar technology

Augmentation of boundary layer lidar (BLL) with polarization Capability

Development of Raman capability to boundary layer lidar for profiling atmospheric water vapor and aerosols

Development of a mobile LIDAR system for profiling clouds and aerosols

Upgradation of boundary layer lidar system with multi-wavelength capability

Major Research Accomplishments

- ✓ Boundary layer lidar (BLL) technology was developed for remote sensing the lower atmospheric aerosols and clouds in 2005. The BLL technology has been filed for patent rights under ISRO with an application number of 597/CHE/2009. The patent application was published in the Indian government patent journal numbered 39/2010 dated 24.09.2010.
- ✓ The BLL technology was licensed in 2009 and commercialized during 2010.
- ✓ The commercial BLL has been named as LAMP stands for *LIDAR for atmospheric measurement and probing*. Five LAMP systems were installed in different parts of India under the Indian LIDAR Network (I-LINK) programme during the period between 2010 and 2012.
- ✓ A dual polarization lidar (DPL) technology was developed during 2009 for remote sensing of boundary layer aerosols and clouds (Fig. 33).
- ✓ The DPL technology has been filed for patent rights under ISRO with application number of 452/CHE/2010. The patent application was published in the Indian government patent journal numbered 34/2011 dated 26.08.2011. The DPL technology was licensed during 2014.
- ✓ A UV Raman lidar (RL) technology was developed for remote sensing the boundary layer water vapor and aerosols during 2011 (Fig. 34).
- ✓ The RL technology has been filed for patent rights under ISRO with application number of 1972/CHE/2012. The patent application was published in the Indian government patent journal numbered 47/2013 dated 22.11.2013. The RL technology is currently posted under ISRO advanced technologies website for technology transfer to Industries.

✓ A near infrared wavelength lidar technology was developed during 2013 for profiling boundary layer during convective periods. The lidar technology was upgraded with beam steering capability during the year 2014-15, which is currently under patent filing process (Fig. 35).

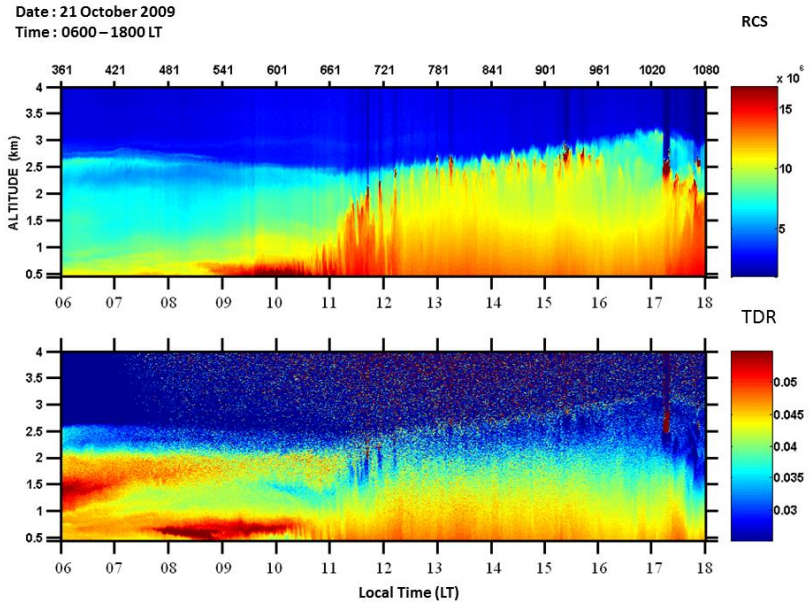


Figure 33. *The Dual polarization Lidar observations of lower atmosphere during daylight hours on 21 October 2009 between 0600 and 1800 LT clearly showing the convective boundary layer (CBL) development and presence of thin aerosols layers in the free troposphere. The bottom panel shows the variation of total depolarization ratio (TDR) of lower atmospheric aerosols during daylight period over Gadanki.*

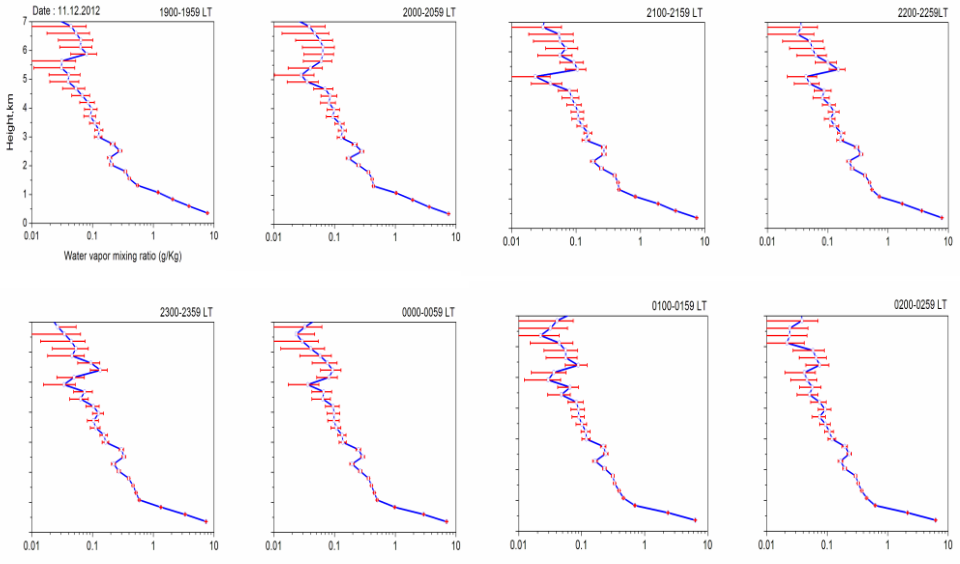


Figure 34.*Sequence of Watervapor mixing ratio profiles obtained from the NARL Raman lidar illustrating a descending humid layer observed on a winter night between 1900 and 0300 LT on 11 December 2012 over Gadanki.*

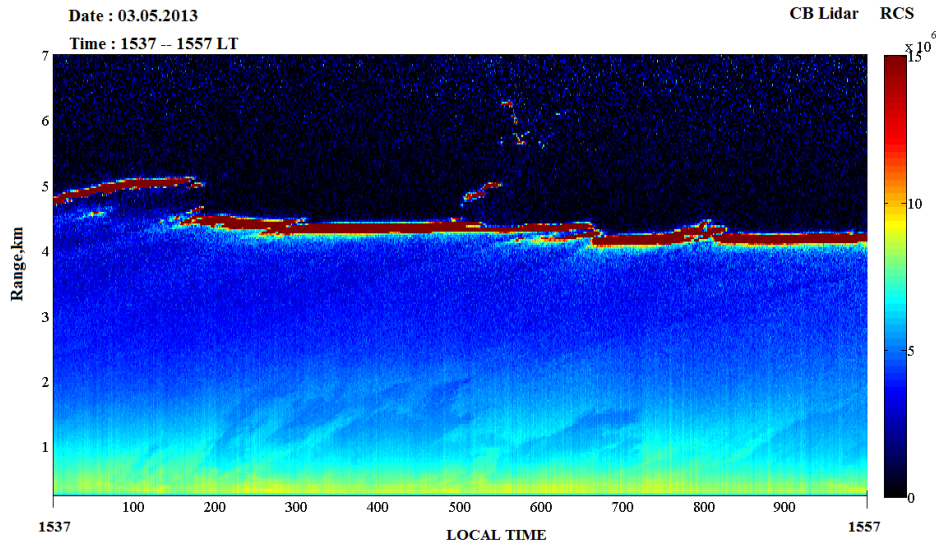


Figure 35. *Time-height cross-section of the range-corrected backscatter measured on 3 May 2013 between 1537 and 1557 hrs LT. The color scale is linear and goes from blue for weak backscattering to Red for strong backscattering. Temporal and spatial resolutions are 1s and 30m, respectively. The vertical axis shown is the range from LIDAR given in kilometre (km) and the horizontal axis represents time in sec from 1537 hrs LT. The high time-resolution range corrected backscatter intensity collected between 1537 and 1557 LT illustrates the detailed temporal variation of cloud base and development of thermals during convective period.*

Way Forward (The group will be addressing the following questions)

- How better various boundary layer processes can be captured using high resolution lidar systems?
- Weather suitable lidar technology can be developed to estimate rain rate and its spatial variability?
- How best lidar technology can be used for micrometeorology and its effect on agriculture?

Work Plan

- **Scanning Cloud Base LIDAR (CBL) system**

  It is proposed to develop a LIDAR using a high power eye-safe pulsed laser as the transmitter and a 350 mm telescope with APD detector as the receiver for profiling the cloud base and covective boundary layer thermals. The system will be installed on the top of a three storey building.

- **Single Detector based polarization LIDAR**

  Using a rotating Glan Thompson prism a single detector based polarization LIDAR scheme will be developed for accurate polarization measurements at three wavelengths from UV to IR.

7.9 Advanced Space-Borne Instrument Development

Group Members

Head: Dr. T V Chandrasekhar Sarma, M.Tech., Ph.D., Scientist/Engineer-SG

Scientific/Technical Staff

Mr. JayantChouragade, BE, Scientist/Engineer-SD
Mr. P Sharath Kumar, B.Tech, Scientist/Engineer-SC

Photograph: 275 Cubic Meter Tethered Ballon and Onboard Instrumentation

Objectives

Development of new atmospheric sensing techniques with state-of-the-art technologies.

Development of flight instrumentation and observation platforms leading to satellite instrumentation. .

Major Accomplishments

✓ **Radio Acoustic Sounding System with MST Radar**

Radio acoustic sounding system (RASS) is a ground-based remote profiling technique to obtain altitude profiles of atmospheric virtual temperature, T_v..RASS system has been designed using the MST radar and acoustic exciters. Modification was made in the MST Radar and acoustic exciter was designed. Each acoustic exciter consists of an approximately hyperbolic horn, subwoofers and associated power amplifiers. Acoustic signal generation is done using a commercial Ethernet controlled audio player that can play .wav files. FMCW chirp waveforms were generated on the computer in the .wav format and downloaded to the player. Sweep range of acoustic signal frequencies was set to 94-125 Hz so as to satisfy Bragg matching condition for temperature range between surface and tropopause based on mean temperature profiles available from radiosonde data. Figure 36shows the atmospheric stability structure represented by the Brunt-Vaisala frequency computed from the virtual temperature profiles obtained using the MST Radar-RASS which was operated over a 72 hour period during 22-25 August 2007.

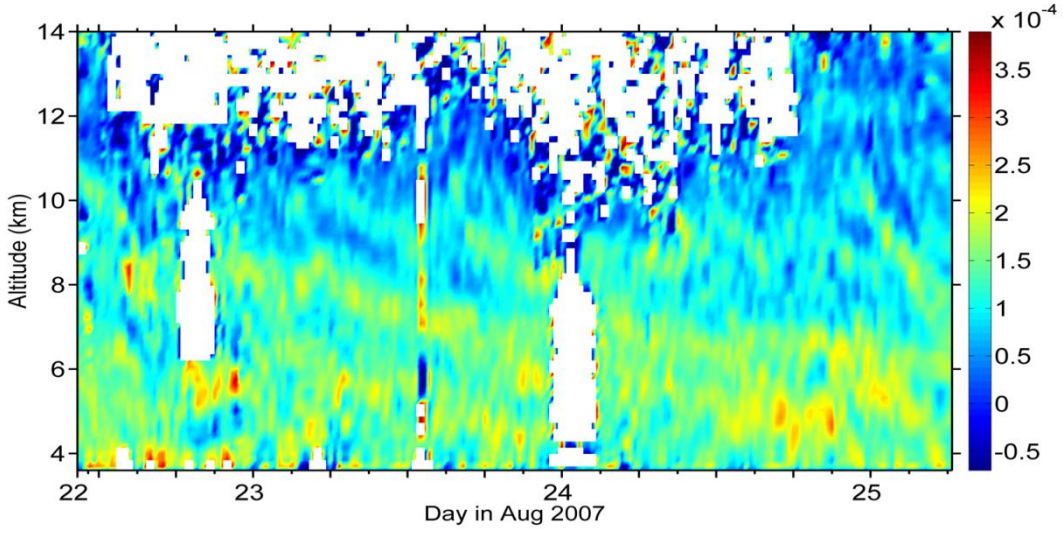


Figure 36. *Brunt Vaisala frequency squared (rad^2 s^{-2}) derived using the virtual temperature measured with the MST Radar-RASS. (JASTP 2011)*

✓ **Radio Acoustic Sounding System with Lower Atmospheric Wind Profiler**

RASS was developed witha wind profiler working at a UHF frequency of 1280 MHz which has been established at NARL. The frequency of the acoustic excitation is chosen so that the wave number of refractive index perturbations induced in the atmosphere along the radar beam is twice the radar RF transmission wave number. Such a relationship is essential to obtain Bragg scatter from the propagating acoustic wavefronts. Taking a temperature measurement range of 45deg C on the ground to about -10deg C at around 7 km altitude, the acoustic frequency range required would be between 3051 Hz and 2775 Hz. Figure 37 shows the colour coded plots of height profiles of virtual temperature observed over a 72 hour period. This result was obtained with 0.25 µs pulse transmission corresponding to a range resolution of 37.5m. The lowest range from which signal is available is around 200 m and the maximum height reached is about 700 m. The lowest heights below 200 m do not have any signal.

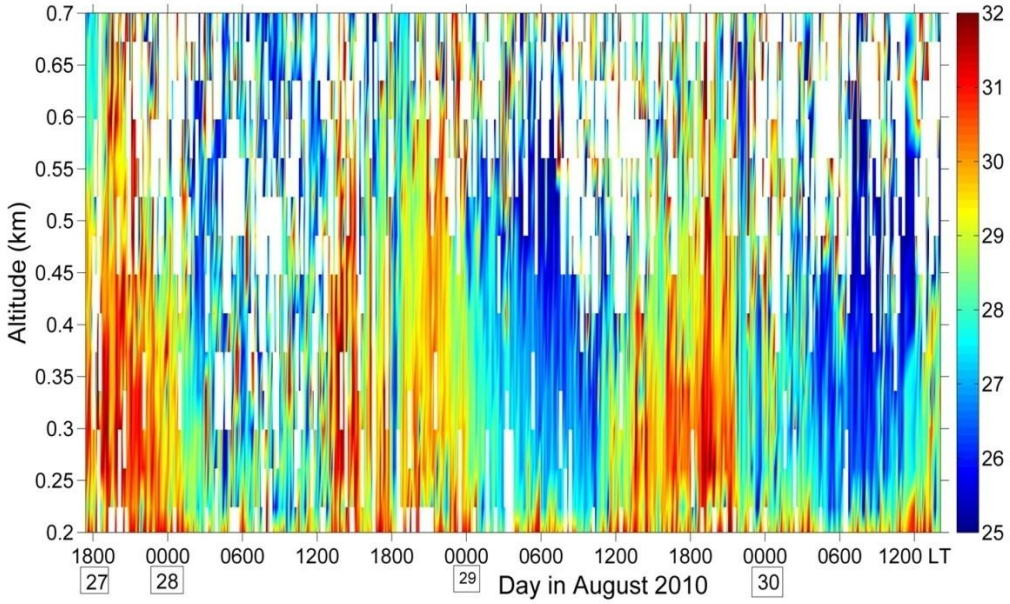


Figure 37.*Colour coded plot of T_v observations using 0.25µs operation of LAWP-RASS in the boundary layer (AMTD 2012).*

With the establishment of RASS systems, and simultaneous availability of a meteorological tower and Rayleigh lidar, a continuous temperature profiling capability from near ground to mesospheric atltitudes is now available at NARL.

✓ **Telemetry System for Balloon Borne Instrumentation**

A 403 MHz band wireless data telemetry system, for use with meteorological balloon based sounders has been developed. The design uses commercially available off-the-shelf transceiver chip ADF7021 for modulation and demodulation of the data to be communicated. The main advantages of using COT transceiver IC are simplified hardware

design, low power and highperformance over wide temperature range. Transmitter and receiver use FPGA based engine to implement control logic, frame formatter/synchronizer, Reed-Solomon channel encoder/decoder, CRC encoder/decoder and receiver interface to PC. The overall system design specifications are given below. Developed subsystems are shown in Figure 38.

Range	: 200-250 Km
Operating frequency	: 400-406 MHz with 100 KHz step size
Modulation	: GFSK
Transmit power	: +20dBm
Data rate	: 2.4 kbps, 4.8 kbps and 9.6 kbps
Transmitter power consumption	: 330 mW peak
No. of receiver channels	: Two
Receiver antenna system	: 1.Monopole 2. RHCQHA
Receiver front-end gain	: 20 dB
Error correction and detection	: RS(255,223) and CRC16
Receiver sensitivity	: -110 dbm @ 4800 bps and PER=10-3

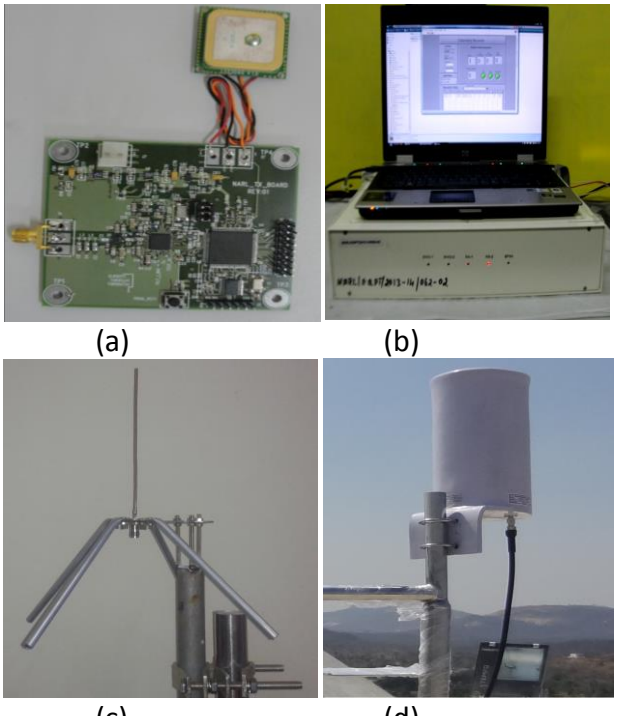


Figure 38. *prototypes (a) Transmitter (b) Receiver (c) Monopole Antenna (d) QHA Antenna*

✓ **Development of Tethered Balloon Observation Platform (TBO)**

NARL has established a wide range of equipment for ground-based remote sensing of the earth's atmosphere. However there is a strong need to obtain data on concentrations of aerosols, trace gases and also probe their interactions with water vapour and other

constituents within the earth's boundary layer. A tethered balloon observation platform (TBOP) was proposed to obtain the height profiles of aerosol and trace gas concentrations, outgoing solar radiation, turbulence intensities etc., up to 4 km in altitude. In order to gain experience, development of a smaller scale system with a hoisting height up to 500 m altitude has been developed. The schematic of the same is shown in Figure 39. The tethered balloon system is analogous to a meteorological tower with variable height. Main specifications of the system are shown below.

Minimum Balloon height	: 500 m
Maximum Balloon Volume	: 275 cu.m.
Maximum Balloon lifting weight	: 130 kg
Maximum Payload weight	: 20 kg
Max. ascent/descent speed	: 10 - 50 m / minute
Power requirement	: 360 W continuous
Maximum continuous observation period	: 8 hours at a stretch
Power supply	: Li-Ion stand alone battery
Battery capacity	: 3.9 kWh
Remote Instrument control and data	: Wi Fi

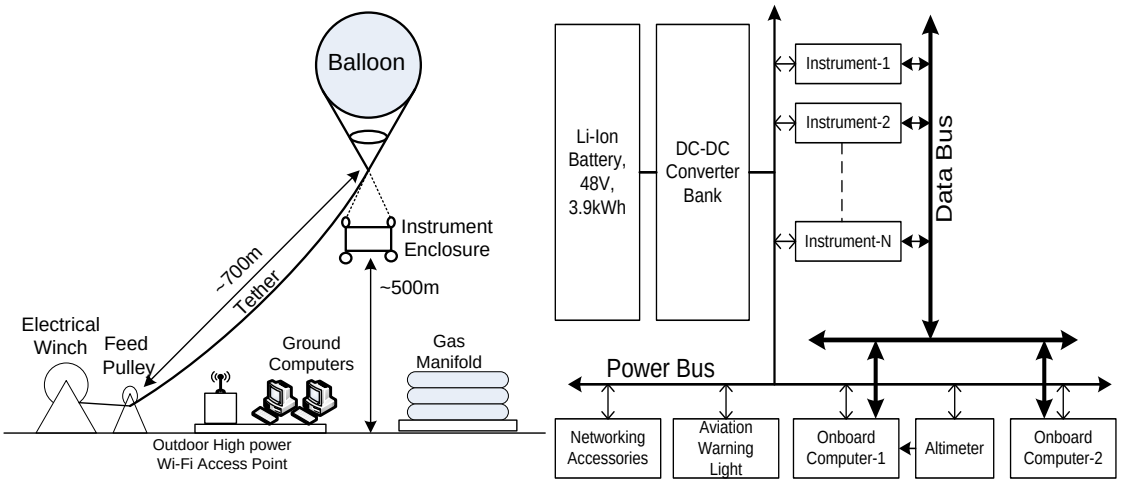


Figure 39. *Schematics of (a) Tethered balloon system (b) Power and Data bus onboard.*

✓ **Electric Field Mill**

A prototype of rotating vane type electric field mill has been developed and tested in the laboratory. Specifications are given in table below.

Electric field range	: ± 20 kV/m
Sensitivity	: ± 10 V/m
Accuracy	: ± 5% of reading
Sampling rate	: 1 Hz

Power Supply	: 12-24 VDC
Interface	: Optical/wireless
Software	: LabVIEW based

Figure 40 shows a simplified block schematic and mechanical apparatus of EFM. Detailed drawings of the mechanical apparatus have been generated. Circuits for signal conditioning, processing and communication interface have been designed after careful selection of components for outdoor use. Simulations of the same are also done using EDA tools. An engineering model is under fabrication with these design inputs.

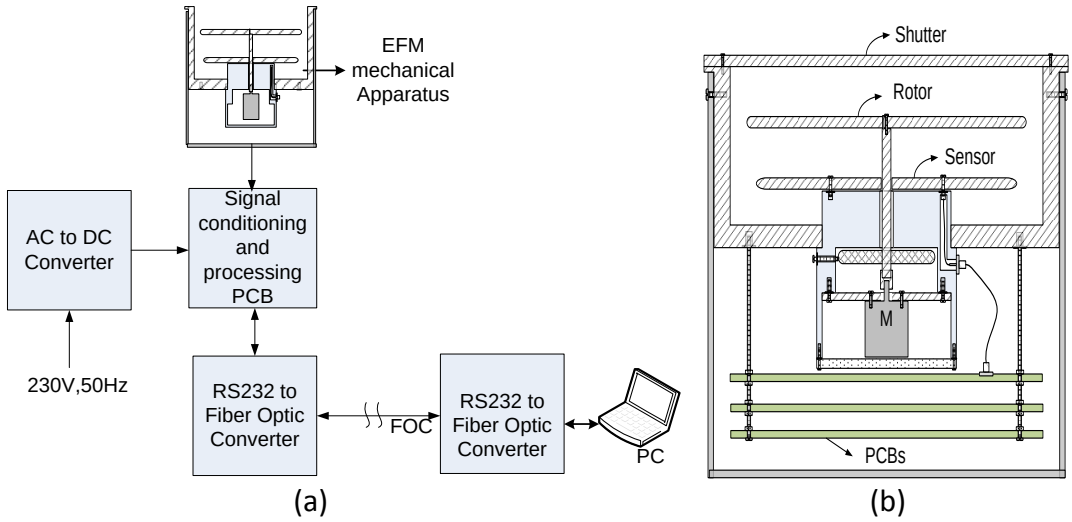
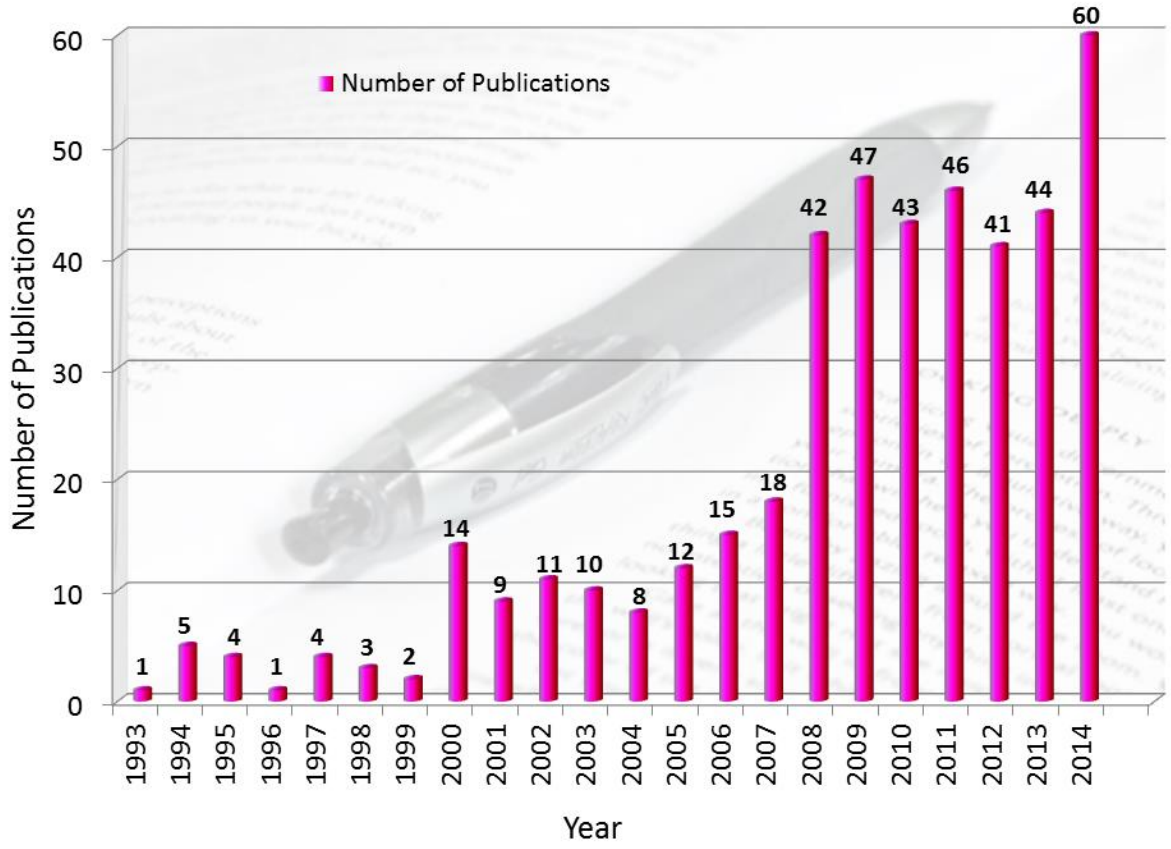


Figure 40. *Electric Field Mill (a) System block diagram (b) Mechanical structure.*

Way Forward (The group will be developing the following techniques/instruments)

- Optical Ozone sensing technique leading to the development of a compact low cost ozonesonde.
- Optical Methane Sensing technique leading to the development of a compact low cost instrument.
- Fiber optic sensors for temperature, humidity and trace gas sensing for miniaturization.
- Ground based Lightning detection and direction finding.
- Satellite based lightning mapping.

8. Publications



NARL has published so far 483 research papers in peer reviewed journals with total citations of 4306 till Sep. 2015.

*** Publications list is enclosed as Annexure**

9. Awards and International Recognitions

A. Jayaraman

- 1988 – Indian National Science Academy Young Scientist award, Earth Sciences
- 1992-2000 - Member, Radiation Commission of the IUGG
- 2001 – Physical Research Laboratory Award, Earth and Planetary Sciences
- 2001 - Lead Author, IPCC Third Assessment Report, Climate Change 2001
- 2002-2007 – Member, Scientific Steering Committee, IGAC of the IGBP
- 2006 - Fellow, Indian Academy of Sciences
- 2007 - Shared the 2007 Nobel Peace Prize awarded to the Intergovernmental Panel on Climate Change (IPCC) as one of the lead authors of the IPCC's Climate Change 2001
- 2010-2012 - Member, Scientific Steering Committee, MAIRS, Chinese Academy of Sciences
- 2010 -2014 Elected as member COSPAR Bureau
- 2011 - Prof. P. R. Pisharoty memorial lecture award, ISRS, SAC, Ahmedabad
- 2012 - Prof. K. R. Ramanathan memorial lecture award by the Indian Geophysical Union
- 2012 - Fellow, Indian Geophysical Union
- 2013 - ISRO Merit Award
- 2014 - 8th International Sardar Patel Award by the SVP Foundation, New Delhi
- 2014 -2018 Elected as Vice-President, COSPAR
- 2015 - Bharat Jyothi Award by IIFS, New Delhi

A. K. Patra

- 2005- Associate fellow, Andhra Pradesh Academy of Sciences
- 2009 - International expert of the MU radar advisory committee, Kyoto University
- 2010 - Received PRL award, Earth and Planetary Sciences
- 2010 - Fellow, Indian Academy of Sciences
- 2012 – Guest editor, IJRSP

T.V. C. Sarma

- 2006 - Ronpaku fellow by Japan Society for Promotion of Science
- 2010 - Senior Member of IEEE
- 2012 – National representative Commission C for URSI

T. Narayana Rao

- Guest editor, IJRSP
- 2014 - Fellow, Andhra Pradesh Academy of Sciences

M. Venkat Ratnam

- 2010 - NASI-SCOPUS Young Scientist award, Earth and Oceanography category
- 2012 - Fellow, Andhra Pradesh Academy of Sciences
- 2014 - Group Leader, WG 3 of ROSMIC under international VarSITI programme
- 2014 - Most cited article award from Terrestrial Atmosphere and Oceanic journal
- 2014 - Guest Editor, JASTP (CAWSES-India Phase-II)
- 2015 - Scientific Discipline Representatives (SDR) from India for SCOSTEP

T.K. Ramkumar

- 2004 - Young Scientist award to attend 2nd IAGA/ICMA Workshop, UK.
- 2005 - Young Scientist award to attend XXVIII General Assembly meeting of URSI.

S. Sridharan

- 2010- Main convener, Structure and Dynamics of the MLT region, Asia-Oceania Geosciences Society meeting held at Hyderabad during 5-9 Jul 2010
- 2011- Guest Editor for the special issue of JASTP on 'Structure and Dynamics and Mesosphere and Lower Thermosphere Region'
- 2012- ISRO RESPOND Coordinator, NARL, Gadanki since April 2012
- 2015- Fellow of 'The Institution of Electronics and Telecommunication Engineers'
- 2015- Fellow of 'Society of Earth Scientists'
- 2015 - Member, International Commission on Middle Atmosphere (ICMA).

Alok Taori

- 2012 - Associate Fellow, Andhra Pradesh Academy of Sciences.
- 2013 - Fellow, Society of Earth Scientists (Lucknow).
- 2013 - Guest Editor, Journal of Advances in Space Research.
- 2014 - Deputy Organizer of session C1.1 of Committee for Space Research (COSPAR).

Nirvikar Dashora

- 2015 - 2014 Editors' Citation certificate for Excellence in Refereeing in JGR-Space Physics by the American Geophysical Union.

Amit Kesarkar

- Member, COSPAR Task Group (TG) on the Group on Earth Observations (GEO).

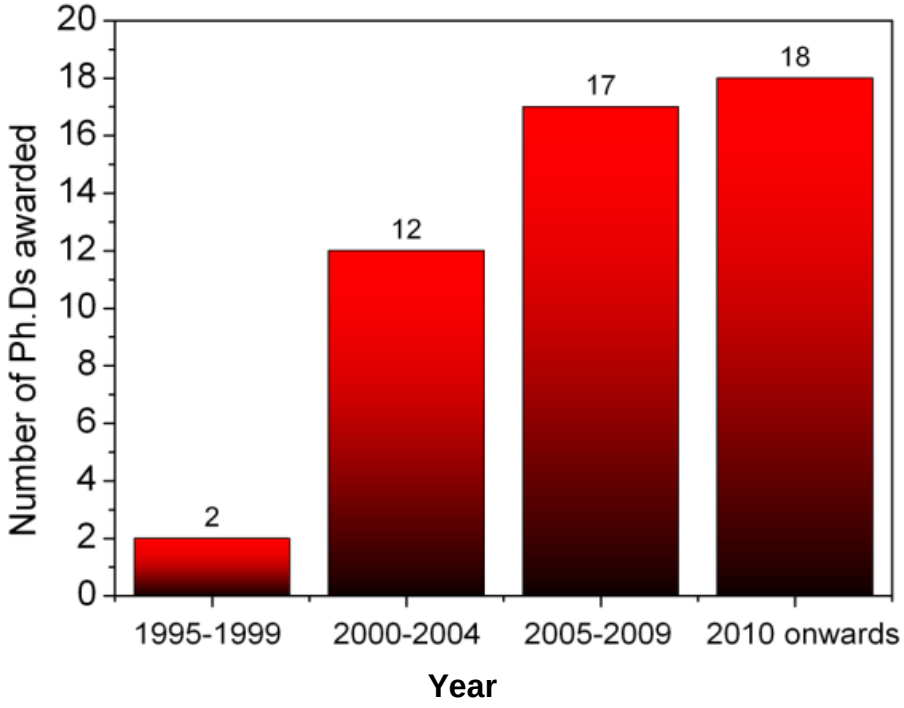
Anish Kumar Nair

- Member, COSPAR Task Group (TG) on the Group on Earth Observations (GEO).

Best paper awards from Conferences/Workshops

Year	Conference/workshop	Best paper Awards
2004	XIII National Space Science Symposium, 17-20 Fe. 2004, Kottayam.	1
2006	11th International workshop on MST Radar, 11-15 December 2006, Gadanki.	2
	XIV National Space Science Symposium, 9-12 Feb. 2006, Visakhapatnam.	2
2008	XV National Space Science Symposium, 26-29 Feb. 2008, Ooty.	1
	First Andhra Pradesh Science Congress, 14-17 Nov. 2008, Hyderabad.	1
2009	Second Andhra Pradesh Science Congress, 14-17 Nov. 2009, Tirupati.	1
2010	XVI National Space Science Symposium, 24-27 Feb. 2010, Rajkot.	2
	Third Andhra Pradesh Science Congress, 14-17 Nov. 2010, Vishakapatnam.	1
2011	Tropical Meteorology (TROPMET), 14-16 Dec. 2011, Hyderabad.	4
	XXXV OSI Symposium of International Conference on Contemporary Trends in Optics and Optoelectronics, 17-19 Jan. 2011, Trivandrum.	1
2012	XVII National Space Science Symposium, 14-17 Feb.2012, Tirupati.	5
	Opportunities and CHAllenges in Monsoon Prediction (OCHAMP), 21-25 Feb. 2012, Pune.	1
	Tropical Meteorology (TROPMET), 19-22 Nov. 2012, Dehradun.	2
	National Symposium on space technology for food and environment and annual conventions, 5-7 Dec. 2012, New Delhi.	1
	International Conference on Geospatial technologies and Applications, 26-29 Feb. 2012, Mumbai.	1
	National Conference on Emerging Trends in Communications & Signal Processing Techniques, 21 Jan. 2012, Tirupati.	1
	International Aerosol Science and Technology Association (IASTA), 11-13 Dec. 2012, Mumbai.	1
2013	Forth Andhra Pradesh Science Congress, 14-17 Nov. 2013, Hyderabad.	1
2014	International Tropical Meteorology (INTROPMET), 21-24 Feb. 2014, Chennai.	2
	XVIII National Space Science Symposium, 29. Jan. -1 Feb. 2014, Dibrugarh.	5
	International conference on Advancements in Materials, Health and Safety towards Sustainable Energy and Environment.	1
2015	International Conference on Climate Change and Disaster Management, 24-29 Feb. 2015, Trivandrum.	1

Number of Ph.Ds awarded



10. National and International Collaborations

NARL collaborates with other National and International organizations/ Universities/ Institutes for further strengthening and expanding its research activities.

National Collaborations (Within ISRO Centres)

Indian Institute of Remote Sensing, Dehradun
Real time weather forecast for disaster monitoring

Indian Institute of Space Science and Technolory, Trivandrum
Ensemble Kalman Filter and 4DVAR data assimilation

ISRO Satellite Tracking Centre, Bangalore
Realization of the X-band polarimetric radar

North East Space Application Centre, Shillong
Weather and Climate modeling; Part of Indian LIDAR network programme;

National Remote Sensing Centre, Hyderabad
Application of remote sensing data for weather, environment and climate modelling; Part of Indian LIDAR network (I-LINK) programme

Physical Research Laboratory, Ahmedabad
Joint scientific experiment to perform isotopic analysis of rain water samples; Investigation on equatorial plasma bubble; Investigation of Sodium airglow intensity variations

Satish Dawan Space Centre, Sriharikota
Wind profiles for launch vehicles; real time weather forecast

Space Application Centre, Ahmedabad
Evaluation of satellite products

Space Physics Laboratory, VSSC, Trivandrum
National level TTD observation Campaign for addressing the Stratosphere - Troposphere Exchange processes; Vertical and lateral coupling investigations using MLT radar network over Indian region

Vikram Sarabhai Space Centre, Trivandrum
Study of mesospheric winds, statistics on vertical and gust winds

National Collaborations (Outside ISRO Centres)

Andhra University, Dept. of Meteorology and Physical Oceanography, Visakhapatnam
Convection Generated Gravity Waves over the Indian Tropical Region by Using MST Radar and Satellite Observations

Aryabhatta Research Institute of Observational Sciences, Nainital
Investigation on meteor flux and disintegration processes; Part of Indian LIDAR network (I-LINK) programme

Doon University, School of Environment & Natural Resource, Dehradun
Chemical data assimilation in air quality models.

Goa University, Department of Chemistry, Goa
Aerosol chemical characterisation

India Meteorological Department, Regional Meterological Center, Chennai
Determination of latent heating of the convective atmosphere using Doppler Weather Radar for the gravity wave studies

Indian Institute of Geomagnetism, Navi Mumbai/ EGRL, Thirunelveli
Vertical and lateral coupling investigations using MLT radar network; Investigation on daytime scintillation; Influence of SSW events on tropics and gravity wave, tidal and planetary wave variabilities in the MLT region

Indian Institute of Technology, Chennai
Characterisation of atmospheric aerosols using Wide Range Aerosol Spectrometer (WRAS)

Indian Institute of Technology, Kharagpur
To understand the turbulence structure during the passage of thunderstorms and boundary layer physics; Investigation on fringe field of equatorial plasma bubble

Indian Institute of Technology, Mumbai
Satellite remote sensing for air quality studies

Indira Gandhi Centre for Atomic Research, Kalpakkam, Tamil Nadu
Joint experiment using NARL's UHF wind profiler for understanding coastal atmospheric boundary layer; Tropical cyclone modeling and data assimilation

National Centre for Medium Range for Weather Forecasting, Ministry of Earth Sciences, Noida
Joint project for improving the quality of Doppler Weather Radar data and using them to validate satellite-derived rainfall

Pune University, Pune
Thunderstorm modelling, land surface modelling and micrometeorology

Sri Venkateswara University, Tirupati
Joint study of the mesospheric processes using the Meteor radar; Regional climate modelling

TIFR Balloon facility, Hyderabad
Study of tropopause aerosol layer; balloon-borne lidar measurements; Part of LIDAR network programme; development of tethered balloon platform

International Collaborations

CNES, France
Strateole-II long duration balloon campaign to study the water vapour transportation in the equatorial upper troposphere and lower stratosphere and the spatio-hetrogeneity of tropical cirrus and its role in modulating the TTL characteristics over the Asian Monsoon region

Karlsruhe Institute of Technology, Institute for Meteorology and Climate Research, Karlsruhe, Germany
Measurement of column averaged abundances of the green house gases CO_2 and CH_4 using FTIR spectrometer.

King Abdullah University of Science and Technology, Thuwal, Kingdom of Saudi Arabia
Development of regional coupled ocean modeling, ensemble and hybrid data assimilation schemes implementation.

Kyoto University, RISH, Japan
Investigation on Daytime 150 km echoing phenomenon, valley region irregularities and longitudinal variability of equatorial plasma bubble, Investigation of seeding mechanisms of quasi-periodic echoes using MU radar; Latitudinal coupling using MLT radar network (IUGONET)

Nagoya University, Japan
Investigation of F region vertical plasma drift

NASA Langley Research Centre, USA
Joint balloon study of the tropopause aerosol layer

National Institute for Space Research (INPE), São José dos Campos, Brazil

Modeling of plasma bubble and fringe field; Non adiabetic Thermodynamics and its application to cumulus parameterization

ONERA, Palaiseau Cedex, France
Coordinated night airglow measurements to study the mesospehric gravity waves

Swedish Institute of Space Physics, Kiruna, Sweden
A VHF wind profiler has been installed at Indian Antarctic station, Maitri under the joint collaboration with NCAOR, Goa, to understand the atmospheric structure and turbulence in the polar troposphere and lower stratosphere.

University of Colorodo, Colorodo, USA
Multi-Nation Campaign to Study Asian Summer Monsoon

University of Hertfordshire, Hatfield, UK
Air quality model inter-comparison and air quality health and exposure modelling

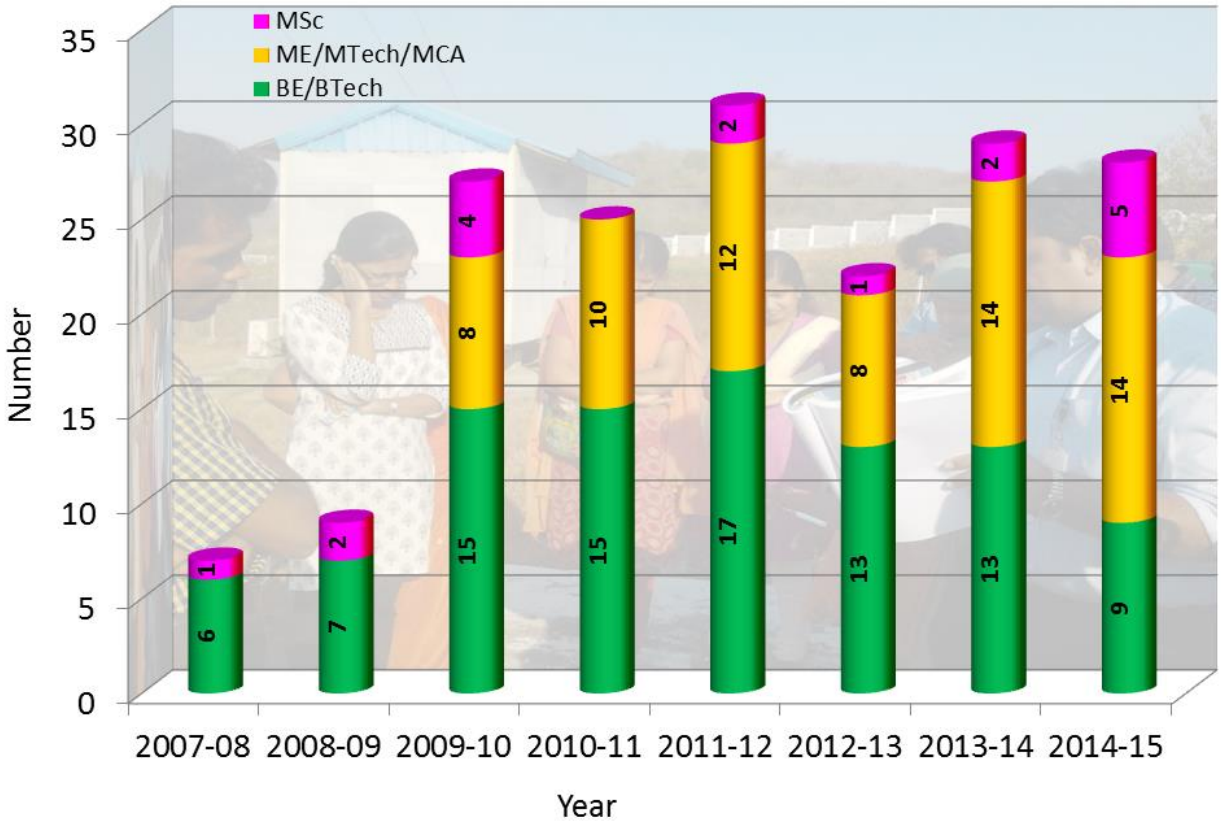
University of Leipzig, Germany, NCAR, USA, IAP, Czech Republic and Chiba University, Japan.
A study on the Role Of the Sun and the Middle atmosphere/thermosphere/ionosphere In Climate (ROSMIC)

University of Lille 1, Villeneuve-d'Ascq, France
Development of OH analyser (FAGE technique)

University of Texas, Dallas, USA
Equatorial electrodynamics using Radar and C/NOFS Satellite

---

11. In-house Project Training



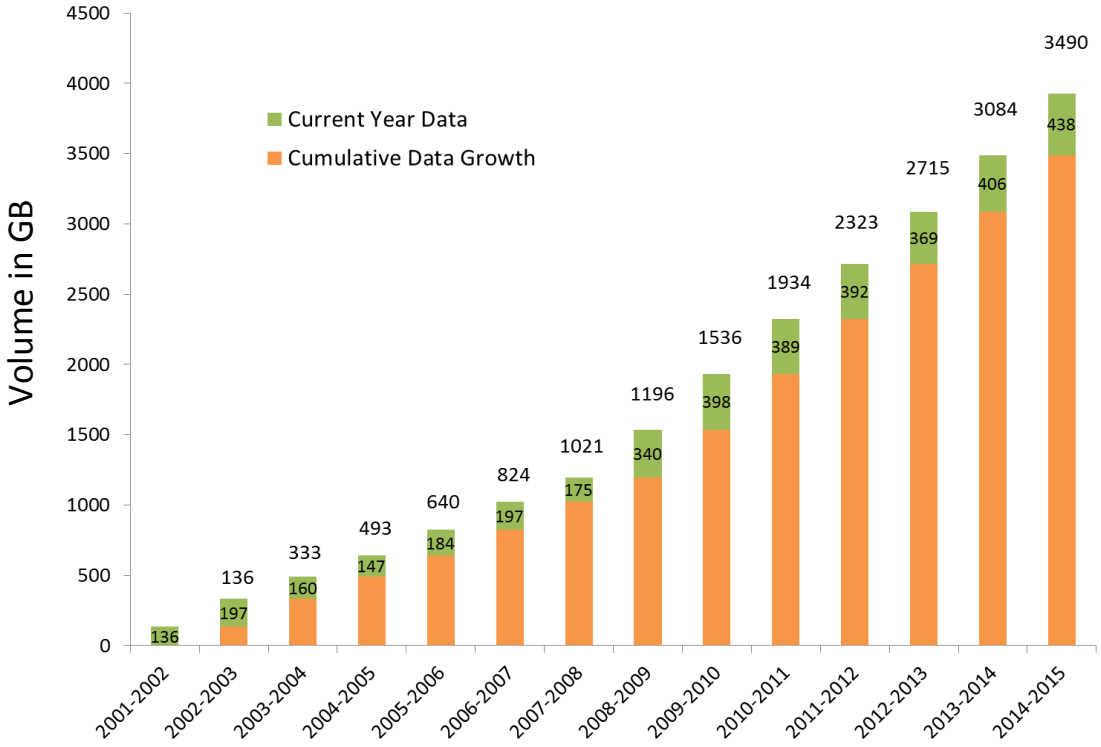
BE/BTech : Each project is carried out by 3 to 4 students for a period of about 8 weeks

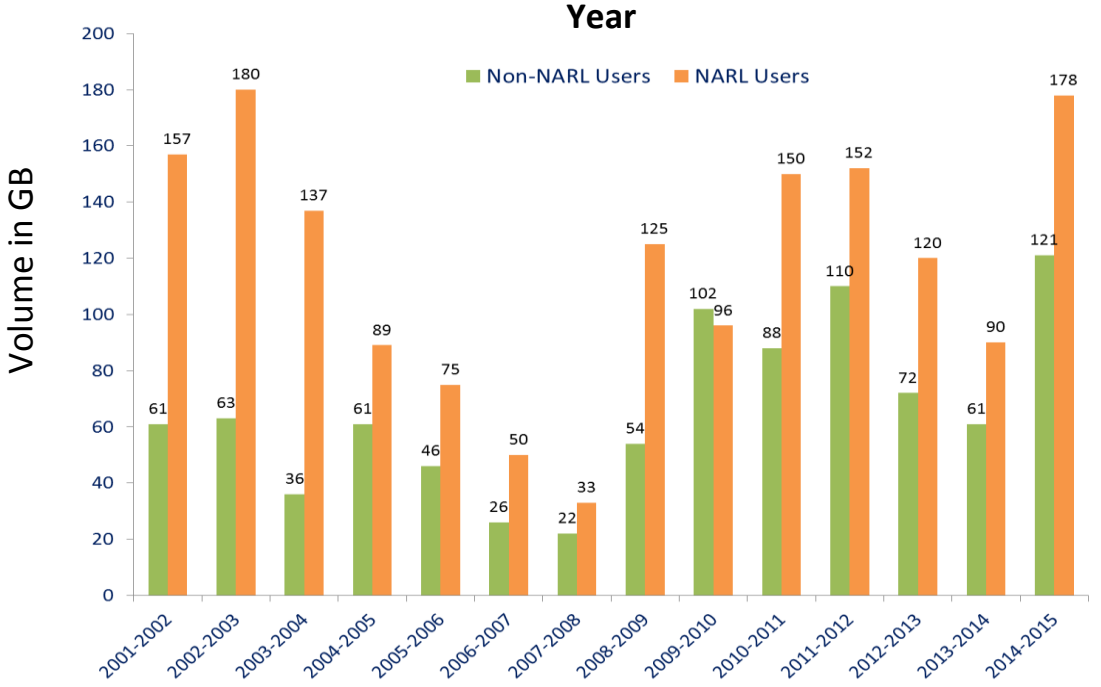
ME/MTech/MCA: Each project is carried out by one student for a period of 6 to 12 months

MSc : Each project is carried out by 1 to 2 students for a period of about 8 weeks

12. Data Archival and Dissemination

NARL also acts as a facility to provide data as well as conducts special experiments to cater the need of the atmospheric science community both nationally and internationally. The chart shown below gives the statistics of cumulative data archival *(top)* and dissemination *(bottom)* from 2001 to Sep 2015.





13. ISRO Sponsored Research (RESPOND)

List of completed RESPOND projects evaluated and recommended from NARL.

Sl.No	Title of the project	Principal Investigator	Budget in million Rupees	Duration
1	ARM processor based control and monitoring system with remote interface for radar transmitters and T/R modules	Dr. K. Nagabhushan Raju, S.K. University, Anantapur	0.941	2009-2011
2	Investigation of tropical convection through observations of gravity waves and troposphere-stratosphere exchange of various parameters	Prof. Gopa Dutta, Anwarul Uloom College, Hyderabad	0.923	2005-2008
3	Advanced Centre for Atmospheric Sciences	Prof. S. Vijaya Bhaskara Rao, S. V.University, Tirupati	3.6	2006-2013
4	MST radar signal processing using wavelets and harmonic decomposition	Dr. G. Ramachandra Reddy,S.V.University, Tirupati Currently at VIT University, Vellore	0.139	2003-2006
5	Investigation on the role of aerosol, cloud and water vapour on the precipitation characteristics of Indian summer monsoon	Dr. V. P. Mahadevan Pillai, University of Kerala, Trivandrum	1.9	2010-2014
6	Technique development (Training and Genetic algorithm methods) for improved satellite rainfall estimation over India	Dr. T. V. Lakshmi Kumar, SRM University, Near Chennai	0.8	2010-2013
7	Lower Atmosphere-mesosphere-ionosphere coupling	Prof. Manashi Roy, Kalpana Chawla Centre for Space and Nano Sciences, Kolkata	0.66	2009-2011
8	Development of cloud cover information over the Indian region using geostationary satellite INSAT / Kalpana / METEOSAT cloud image data	Dr. Satyendara Bhandari, Indian Centre for Climate and Societal Impacts Research, Ahmadabad	1.2	2011-2013

List of ongoing RESPOND projects evaluated and recommended from NARL.

Sl. No.	Title of the project	Principal Investigator	Budget in million Rupees	Duration
1	Satellite Radar and Lidar based studies on vertical coupling of atmospheric dynamics and ionospheric electrodynamics	Dr. S. Venkataramana Reddy, S.V. University, Tirupati	0.98	Started in June 2014 (3 year project)
2	Atmospheric Boundary Layer (ABL) and cloud characteristics and monitoring of aerosol over Cochin	Dr. C. A. Babu CUSAT, Cochin	1.67	Started in July 2012 (3 year project)
3	Spatial & Temporal variability of total ozone over the tropics - special reference to the Indian scenario during the Asian summer circulation	Dr. V. Madhu CUSAT, Cochin	0.51	Started in March 2012 (3 year project)
4	MST Radar Signal Processing using Empirical Mode Decomposition and Hilbert Huang Transform	Dr. N.Padmaja SreeVidyanikethan EngineeringCollege, Tirupati	1.44	Started in Oct 2014 (2 year project)
5	Understanding and Characterization of Systematic Erros in the WRF-ARW Boundary layer parameterization over the Bhubaneswar and in neighbourhood regions	Dr. Sandeep Pattnaik , Indian Institute of Technology, Bhubaneswar, Odisha	1.8	Sanctioned in May 2014 (3 year project)
6	Evolutionary neurofuzzy rainfall prediction system	Dr.B. Sowmya Dhanalakshmi College of Engineering, Chennai	1.3	Sanctioned in June 2014 (2 year project)
7	Surface measurements of atmospheric radioactivity and its influence on electrical conductivity of the Earth's atmosphere	Dr. Kamsali Nagaraju Bangalore University, Bangalore	1.26	Sanctioned in Sep 2014 (3 year project)
8	Advanced Centre for Atmospheric Sciences	Dr. S. Vijaya Bhaskara Rao, S.V. University, Tirupati	6.8	Sanctioned in Apr 2015 (5 year project)

14. Workshops/Conferences/Schools Organized

1. First winter school on Indian MST radar was organized jointly by NMRF, Gadanki and S. V. University, Tirupati during 28 January – 4 February, 1991.
2. Second winter school on Indian MST radar was organized jointly by NMRF, Gadanki and S. V. University, Tirupati during 30 January – 4 February, 1995.
3. Second workshop on MST radar results was organized jointly by NMRF, Gadanki and S. V. University, Tirupati, 23-24 May 1995.
4. Eighth International Workshop on Technical and Scientific Aspects of MST Radar (MST8) was organized by NMRF, ISRO at Bangalore, India during 15-20 December 1997.
5. III user scientists' workshop on MST radar results, 6-7 February, 1997.
6. International School on Atmospheric Radar was jointly organized by S. V. University, Tirupati and NMRF, Gadanki during 10-13 December 1997.
7. ISTEP working group III (WG3) meeting, NMRF, Gadanki, August, 1998.
8. III winter school on MST radar was organized jointly by NMRF, Gadanki and S. V. University, Tirupati during 5-9 March 2001.
9. Fifth user scientist workshop was organized jointly by NMRF, Gadanki and S. V. University, Tirupati on 10 March 2001.
10. Brain Storming Session on the Results of Equatorial Wave Campaigns of 1999 and 2000, NMRF, Gadanki, 16 August 2002.
11. Third International School on Atmospheric Radar (ISAR-3) was organized by Prof. J. Roettger and Prof. D. Narayana Rao, Director, NMRF at International Center for Theoretical Physics, Trieste, Italy during 25 November - 13 December 2002.
12. Workshop on Studies of Tropical Mesoscale Convection Systems (TMCS) held at NMRF Gadanki on 13-14 March 2002.
13. VI User Scientists' workshop, NMRF, Gadanki, 26-27 February 2003.
14. National Science Day celebrations, NMRF, Gadanki, 28 February 2003.
15. Training Programme on Atmospheric Sciences and Atmospheric Remote Sensing Techniques was organized by NMRF, Gadanki for Post-Graduate Science students and final year graduate engineering students, 02-20 June 2003.
16. Hindi week celebrations, NMRF, Gadanki, 8-14 September 2004.
17. IV Winter School on Indian MST Radar was organized jointly by NMRF, Gadanki and UGC-SVU Center for MST Radar Applications, S. V. University, Tirupati, 21-30 January 2004.
18. National Science Day celebrations, NMRF, Gadanki, 28 February 2004.
19. VII User Scientists' Workshop was organized jointly by NMRF, Gadanki and UGC-SVU center for MST Radar Applications, S. V. University, Tirupati, 5-7 July 2004.
20. Workshop meeting on National Strategies and Technologies for Weather Modification and Cloud Seeding organized jointly by NMRF, Gadanki and S. V. University, Tirupati, 29 September 2004.

21. Colloquium on International Network of Tropical Atmosphere Radars (INTAR) was organized jointly by NMRF, Gadanki and S. V. University, Tirupati, 20-22 January 2005.
22. Colloquium on International Network of Tropical Atmosphere Radars (INTAR), NARL, Gadanki, 20-22 January 2005.
23. Workshop on Radar Interferometry and Imaging (WRII-NMRF 2005), NMRF, Gadanki 24-25 January 2005.
24. National Science Day celebrations, NMRF, Gadanki, 28 February 2005.
25. One day Hindi workshop, NMRF, Gadanki, 12 July 2005.
26. GPS Radio Occultation workshop, NARL, Gadanki, 19-20 April 2005.
27. Two day seminar on "Recent Trends in Modern Communications" was organized jointly by NARL, Gadanki and the Institute of Electronics and Telecommunication Engineers, Tirupati sub center, 25-26 November 2006.
28. One day Hindi seminar on Space Technology in the 21st Century, NARL, Gadanki, 22 December 2006.
29. Workshop on "Atmospheric probing using lidars", NARL, Gadanki, 20-21 November 2006.
30. Eleventh International Workshop on Technical and Scientific Aspects of MST Radar (MST11), Gadanki/Tirupati was organized by NARL, Gadanki during 11-15 December 2006.

31. CAWSES-India workshop, NARL, Gadanki, 21-23 May 2007.
32. GPS Radio Occultation Workshop, 19-20 April, 2007, NARL, Gadanki.

33. School on Radar and Lidar Remote Sensing of the Atmosphere (RALID 2k7) was jointly organized by NARL, Gadanki and S. V. University, Tirupati, 7-11, March 2007.

34. Megha-Tropiques (MT) data validation plan meeting, NARL, Gadanki, 31 July 2008.
35. National school on Atmospheric Radars and Lidars was organized jointly by NARL, Gadanki and S. V. University, Tirupati, 25-29 March 2008.
36. Workshop on ROSA data inversion, validation and utilization, NARL, Gadanki 10-11 January 2008.

37. Data analysis workshop on Study of Atmospheric Forcings and Responses (SAFAR), NARL, Gadanki, 30-31 January 2009.
38. CAWSES-India Phase II Science programme workshop, NARL, Gadanki, 9-11 July 2009.
39. Workshop on Science and Technology Initiatives in Atmospheric Science for Engineering Staff, NARL, Gadanki, 25-26 November 2010.
40. NARL organized one day workshop on High Performance Computing Training at ISAC, Bangalore on March 18, 2010.
41. NARL-RISH Kyoto University Discussion Meeting/Workshop on Recent Advances in Observational Studies of the tropical atmosphere and ionosphere, NARL, Gadanki, 28-29 March 2011.
42. National conference on Advances in Atmospheric Remote Sensing, Weather Prediction & Climate Change (ARWPCC-2011) was organized jointly by NARL, Gadanki and S. V. University, Tirupati under UGC-CAS program, 10-11 March 2011.
43. One day users' training program on High Performance Computing and Applications was arranged at NARL, Gadanki on 21 September 2011.
44. NARL organized Intel – NARL training workshop on High Performance Computing and Parallel Programming on April 5- 6, 2013 at NARL, Gadanki.

ICTS program on Advanced Dynamical Core Modeling for Atmospheric and Oceanic Circulations
National Atmospheric Research Laboratory, Gadanki, India
18-23 February 2013
ICTS

45. An international workshop on Advanced Dynamical Core Modeling (ADCM) for Atmospheric and Oceanic Circulation was held at NARL, Gadanki during 18-23 February 2013.
46. A 3-day National workshop on CAWSES India Phase-2 (NAWCIP-2013) was held at NARL, Gadanki during 29 April – 1 May 2013.
47. Lectures, Hands-on Training & Lab visit program are conducted at NARL, Gadanki for the participants of second SERB school on Fundamentals of Radars for Atmospheric Research (FORFAR II) during 24-28 February 2014.

15. Public Outreach

It is NARL's constant endeavor to reach public, in particular school and college students and teachers, to share the excitement of doing atmospheric research and technological development. All Fridays are earmarked for such visits. About 15,000 visitors from 125 Institutes visited NARL since 2009, including students and teachers from High schools, Polytechnics, Science and Engineering colleges and personnel from Department of Defense, NCC etc. University faculties also visit NARL as part of their conference, workshop and faculty development programs.

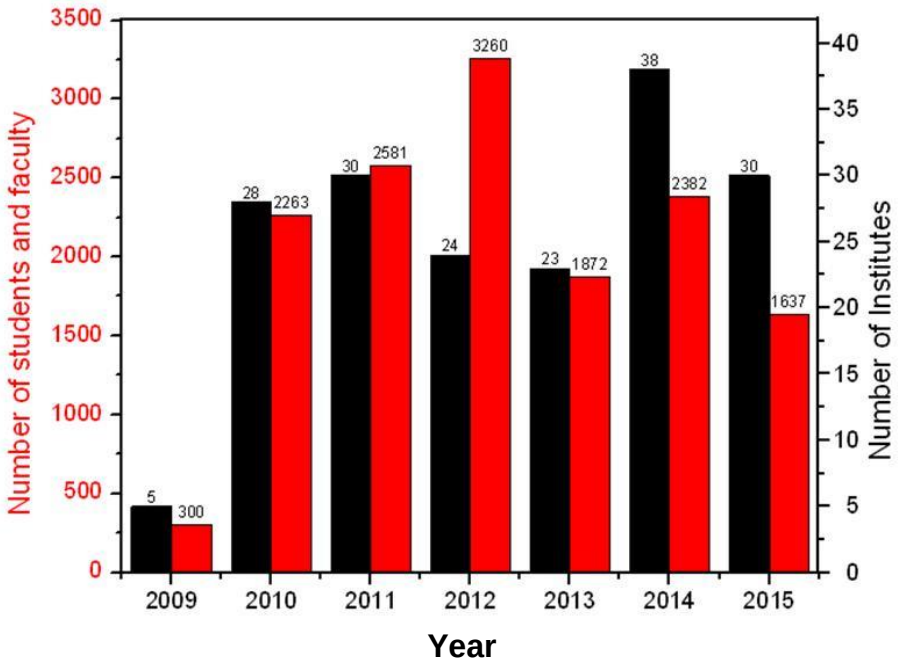


Figure shows the yearwise statistics of number of visitors to NARL.

Annexure (Publications List)

1993

1. Preliminary results using ST mode of the Indian MST radar: Measurement of vertical velocity, G. Viswanathan, P. Kishore, P. B. Rao, A. R. Jain, R. Aravindan, P. Balamuralidhar and S. H. Damle, Ind. J. Radio & Space Phy., 22, 97-102, 1993 (*Citations: Nil*).

1994

2. Observations of low latitude spread-F using ST mode of the Indian MST radar, P. B., Rao, A. R. Jain and V. K. Anandan, Ind. J. Radio & SpacePhy., 23, 93-100, 1994 (*Citations: Nil*).
3. High-resolution measurements of horizontal winds using ST mode of the Indian MST radar: A comparison with balloon measurements, P. Kishore, P. B. Rao, A. R. Jain, P. Balamuralidhar, S. H. Damle, G. Viswanathan and G. V. Rama, Ind. J. Radio & Space Phy., 41-51, 1994 (*Citations*: 4).
4. Some observations of tropical tropopause using ST mode of the Indian MST radar: Multiple stable layer structure, Y. Jaya Rao, A. R. Jain, V. K. Anandan and P. B. Rao, Ind. J. Radio & Space Phy., 23, 75-85, 1994 (*Citations*: 9).
5. Radar signal spectra dependence on the pulse width: Observations using ST mode of the Indian MST radar, A. R. Jain, P. B. Rao and Y. Jaya Rao, Radar signal spectra dependence on the pulse width: Observations using ST mode of the Indian MST radar, Ind. J. Radio & Space Phys., 23, 86-92, 1994 (*Citations: Nil*).
6. Indian MST radar-An overview, P. B. Rao, A. R. Jain G. Viswanathan and S. H. Damle, Ind. J. Radio & Space Phys., 23, 1-5, 1994 (*Citations*: 3).

1995

7. Applications of Indian MST radar: Some meteorological aspect, A. R., Jain, Y. Jaya Rao and A. K. Patra, Vayu mandal, 92, 1995 (*Citations: Nil*).
8. First observations of equatorial spread F from Indian MST radar, A. K., Patra, V. K. Anandan, P B. Rao and A. R. Jain, Radio Sci., 30. 1159-1165, 1995 (*Citations*: 27).
9. Indian MST radar 1. System description and sample vector wind measurements, P. B. Rao, A. R. Jain, P. Kishore, P. Balamuralidhar, S. H. Damle and G. Viswanathan, Radio Sci., 30, 1125-1138, 1995 (*Citations*: 265).
10. Indian MST radar 2. First scientific results in ST mode, A. R. Jain, Y. Jaya Rao, P. B. Rao, V. K. Anandan , S. H . Damle, P. Balamuralidhar and A. Kulkarni, Radio Sci., 30, 1139-1158, 1995 (*Citations*: 21).

1996

11. First VHF radar observations of tropical latitude E-region field aligned irregularities, R. K., Choudhary, K. K. Mahajan, S. Singh, K. Kumar and V. K. Anandan, Geophys. Res. Lett., 23, 3683-3686, 1996 (*Citations*: 16).

1997

12. Radar observations of 2.8 m equatorial spread-F irregularities, A. K. Patra, P. B .Rao, V. K. Anandan and A. R. Jain, J. Atmos. Sol.Terr. Phys., 1633-1641, 1997 (*Citations*: 17).
13. Radar observations of up and downdrafting plasma depletions associated with the equatorial spread F, P. B. Rao, A. K. Patra, T. V. Chandrasekhar Sarma, B V KrishnaMurthy, K S V Subbarao and S. S. Hari, Radio Sci., 32, 1215-1227, 1997 (*Citations*: 22).
14. Ionization hole campaign—a coordinated rocket and ground-based study at the onset of equatorial spread-F: first results, R. Sridharan, H. Chandra, S.R. Das, R. Sekar, H.S.S. Sinha, D. Pallam Raju, R. Narayanan, Shika Raizada, R.N. Misra, R. Raghavarao, G. D. Vyas, P. B. Rao, P.V.S. Ramarao, V.V. Somayajulu, V.V. Babu, A. D. Danilov, J. Atmos. Sol. Terr. Phys., 59, 2051-2067, 1997 (*Citations*: 16).
15. Aspect sensitivity of the received radar backscatter at VHF: Preliminary observations using the Indian MST radar, A. R. Jain, Y. Jaya Rao and P. B. Rao, Radio Sci., 32, 1249-1260, 1997 (*Citations*: 17).

1998

16. Stratosphere-troposphere ozone exchange observed with the Indian MST radar and a simultaneous balloon-borne ozonesonde, T. K. Mandal, J. Y. N. Cho, P. B. Rao, A. R. Jain, S. K. Peshin, S. K. Srivastava, A. K. Bohra and A. P. Mitra, Radio Sci., 33, 861-893, 1998 (*Citations*: 8).
17. Small-scale (~3 m) E region irregularities at and off the magnetic equator, B. V. Krishna Murthy, S. Ravichandran, K. S. Viswanathan and K. S. V. Subbarao, A. K. Patra and P. B. Rao, J. Geophys. Res., 103, 20761-20772, 1998 (*Citations*: 43).
18. Recent advances on equatorial spread F, P. B. Rao and A. K. Patra, Proc. Ind. National Sci. Acad., A3, 127-137, 1998 (*Citations*: 1).

1999

19. Layered clouds in the Indian monsoon region, Proc. Indian Acad. Sci., M. K., Rama Varma, G. C. Asnani, P. S. Salvekar, A. R. Jain, D. Narayana Rao, S. Venkoba Rao, P. Kishore and M. Hareesh, Earth Planet Sci., 18, 287-295, 1999 (*Citations*: 1).
20. High-resolution radar measurements of turbulent structure in the low-latitude E region, A. K., Patra and P. B. Rao, J. Geophys. Res., 104, 24667-24673, 1999 (*Citations*: 15).

2000

21. Indian MST radar-An overview of the scientific programmes and results, A. R. Jain, D. Narayana Rao and P. B. Rao, Ind. J.of Radio & Space Physics, 29, 149-171 (*Citations*: 3).
22. Facilities co-located at NMRF, Gadanki (13.5°N, 79.2°E), A. R., Jain, Ind J. Radio & Space Phys, 172-176, 2000 (*Citations*: 1).
23. Patchy layered structure of tropical troposphere as seen by Indian MST radar, G. C. Asnani, M. K. R. Varma Raja, D. N. Rao, P.S. Salvekar, P. Kishore, T.N. Rao, M. Venkat Ratnam and P.B. Rao, Ind. J.of Radio & SpacePhysics, 29, 182-191, 2000 (*Citations*: 1).
24. Signature of passage of ITCZ on wind profiles from MST radar at Gadanki, B. V. Krishna Murthy, S. R. Prabhakaran Nair, K. Revathy, G. Mridula, K. Satheesan, A. R. Jain, Ind J. Radio & Space Phys., 29, 199-202, 2000 (*Citations: Nil*).
25. Oscillation of tropical tropopause during passage of atmospheric waves, Y. Jaya Rao, A R. Jain, Ind J. Radio & Space Phys., 29, 203-209, 2000 (*Citations*: 1).
26. Characteristics of atmospheric winds, associated shear and turbulence: Indian MST radar measurement during summer monsoon season, A. K. Ghosh, A. R., Jain and V. Sivakumar, Ind J. Radio & Space Phys., 29, 222-230, 2000 (*Citations*: 6).
27. Preliminary results of equatorial wave experiment conducted from January 18, 1999 to March 5, 1999 with Lidar at Gadanki, B. V. Krishna Murthy, S. R. Prabhakaran Nair, K. Revathy, G. Mridula, K. Satheesan, K. Parameswaran, M. N. Sasi, Geetha Ramkumar, Prabha R. Nair, V. Deepa, Y. Bhavani Kumar, K. Raghunath, V. Sivakumar T. Rajendraprasad and M. Krishnaiah, Ind. J. Radio & Space Phys., 29, 231-234, 2000 (*Citations: Nil*).
28. Indo-Japanese Lidar observations of aerosols over a tropical latitude, K. Raghunath, Y. Bhavani Kumar, P. B. Rao, K. Mizutani, T. Aoki, M. Yasui and T. Itabe, , Ind. J. Radio & Space Phys., 29, 239-244, 2000 (*Citations*: 1).
29. Thin aerosol clouds at tropopause level, B. V. Krishna Murthy, S. R. Prabhakaran Nair, K. Revathy, K. Satheesan K. Parameswaran, Prabha R. Nair, K. Krishna Murthy, P. B. Rao, Y. Bhavani Kumar, K. Raghunath and M. Krishnaiah, Ind J. Radio & Space Phys., 29, 245-248, 2000 (*Citations*: 3).
30. Detection of Pre-sunrise echoes at mesospheric heights, M. Venkat Ratnam, T. N. Rao, D. N. Rao, S.V.B. Rao, Y.B. Kumar and K. Raghunath, Ind. J. Radio & Space Phys., 29, 258-261, 2000 (*Citations: Nil*).
31. Preliminary results on equatorial spread-F irregularities by VHF and HF radars,R., Sekar, E. A. Kherani, K. S. Viswanathan, A. K. Patra, P. B. Rao, C. V. Devasia, K. S. V. Subbarao, D. Tiwari and N. Ramachandran, Ind. J. Radio & Space Phys., 29, 262-271, 2000 (*Citations*: 2).
32. Middle atmospheric temperature measurements using a ground based lidar from low latitude, Y. Bhavani Kumar, V. Sivakumar, P. B. Rao, M. Krishnaiah, K. Mizutani, T. Aoki, Y. Motoaki, T. Itabe, Ind J. Radio & Space Phys., 29, 222-230, 2000 (*Citations*: 16).
33. Altitude profiles of temperature from 4-80 km over the tropics from MST radar and Lidar, K. Parameswaran, M. N. Sasi, Geetha Ramkumar, P. R. Nair, V. Deepa, B. V. Krishna Murthy, S. R. Prabhakaran Nayar, K. Revathy, G. Mrudula, K. Satheesan, Y. Bhavani Kumar, K. Raghunath, V. Siva Kumar, T. Rajendra Prasad and M. Krishnaiah, J. Atmos. Sol.Terr. Phys., 62 1327-1337, 2000 (*Citations*: 38).

34. Observations of Tropical convection events using Indian MST radar: First results, A R. Jain, Y. J. Rao, A. K. Patra, P. B. Rao, G. Viswanathan and S. K Subramanian, Quarterly J. Royal Met. Soc., 126, 3097-3155, 2000 (*Citations*: 17).

2001

35. Lidar observations of aerosol layers just below the tropopause level during IFP-INDOEX, K., Parameswaran, Prabha R. Nair, K. Krishna Moorthy, B. V. Krishna Murthy, S. R. Prabhakaran Nayar, K. Revathy, K. Satheesan, P. B. Rao, Y. Bhavanikumar, K. Raghunath and M. Krishnaiah, Curr. Sci., 80, 166-170, 2001 (*Citations*: 4).
36. Interaction of two long wavelength modes in the nonlinear numerical simulation model of equatorial spread F, R. Sekar, E. A. Kherani, P. B. Rao and A. K. Patra, J. Geophys. Res., 106, 24765-24775, 2001 (*Citations*: 15).
37. Lower atmospheric wind profiler at Gadanki, tropical India: Initial results, K.K. Reddy, T. Kozu, K. Nakamura, Y. Ohno, P. Srinivasalu, V. K. Anandan, A. R. Jain, P. B. Rao, R. Ranga Rao, G. Viswanathan, D. Narayanarao, Meteorlogische Zetschrift, 10, 457-468, 2001 (*Citations*: 17).
38. Diurnal and seasonal variability of turbulence parameters observed with Indian mesosphere-stratosphere-troposphere radar, D. N. Rao, T. N. Rao, M. VenkatRatnam, S. T. Raman, S. V. B. Rao, P. Srinivasulu and P. B. Rao, Radio Science, 36, 1439-1457, 2001 (*Citations*: 35) .
39. Lidar measurements of mesospheric temperature inversion at a low latitude, V. Siva Kumar, Y. Bhavani Kumar, K. Raghunath, P. B. Rao, K. Mizutani, T. Aoki, M. Yasui and T. Itabe, Ann. Geophys, 19, 1039-1044, 2001 (*Citations*: 40).
40. MST radar and polarization lidar observations of tropical cirrus, Y., Bhavani Kumar, V. Siva Kumar, A.R. Jain, P.B. Rao, Ann. Geophy., 19, 873-882, 2001 (*Citations*: 17).
41. Height-time-structure of VHF back-scatter from stable and turbulently mixed atmosphere layers at tropical latitudes, A. R. Jain, Y. Jaya Rao and N. S. Mydhili, J. Atmos. Sol.Terr. Phys., 63, 1455-1463, 2001 (*Citations*: 8).
42. VHF radar observation of atmospheric winds, associated shears and C_n^2 at a tropical location: interdependence and seasonal pattern, A. K. Ghosh, V. SivaKumar, K. Kishore Kumar and A. R Jain, Ann. Geophys., 19, 965-973, 2001 (*Citations*: 15).
43. Spectral analysis of atmospheric radar signal using higher order spectral estimation technique, V. K. Anandan, G. Ramachandra Reddy, IEEE Transactions on Geoscience and remote sensing 39, 2001 (*Citations*: 20).

2002

44. Equatorial waves in temperature in temperature in the altitude range 4 to 70 km, B. V. Krishna Murthy, K. Sathesan, K. Parameswaran, M. N. Sasi, Geetha Ramkumar, Y. Bhavanikumar, K. Raghunath and M. Krishnaiah, Quart. J. Royal Met. Soc., 128, 819-838, 2002 (*Citations*: 16).
45. Application of facilities at NMRF, Gadanki in the area of metorology and coupling processes in the atmosphere-A brief review and future prospects, A. R. Jain and V. K. Anandan, Ind. J. Radio & Space Phys., 31, 357-368, 2002 (*Citations*: 1).

46. Low altitude quasi-periodic radar echoes observed by the Gadanki VHF radar, C. J. Pan, P. B. Rao, Geophys. Res. Lett., 29, 10.1029/2001GL014331, 2002 (*Citations*: 16).
47. Evidence of intermediate layer characteristics in the Gadanki radar observations of the upper E region field aligned irregularities, A. K. Patra, P. B. Rao, V. K. Anandan, A R Jain and G. Viswanathan, Geophys. Res. Lett., 29, 1696, 10.1029/2001GL013773, 2002 (*Citations*: 20).
48. Evidence of kilometer-scale waves in the lower E region from high resolution VHF radar observations over Gadanki, A. K. Patra, S Sripathi, V. Siva Kumar and P. B. Rao, Geophys. Res. Lett., 29, 1499, 10.1029/2001GL013340, 2002 (*Citations*: 21).
49. Equatorial E region irregularities: A review of recent observations, R. Raghavarao, A. K. Patra and S. Sripathi, J. Atmos. Sol. Terr. Phys., 64, 1435, 2002 (*Citations*: 9).
50. On the interpretation of the VHF radar echoes from the equatorial lower E region, A. K. Patra, Geophys. Res. Lett., 29, 1695, 10.1029/2001GL013358, 2002 (*Citations*: 6).
51. Observations on stratospheric-mesospheric-thermospheric temperatures using Indian MST radar an co-located LIDAR during Leonid meteor shower (LMS), R. Selvamurugan, C. V. Devasia, A. R. Jain, C. Raghava Reddi, P. B. Rao and R. Sridharan, Ann. Geophys., 20, 1869-1876, 2002 (*Citations*: 1).
52. Planetary boundary layer and precipitation studies using lower atmospheric wind profiler over tropical India, K. Krishna Reddy, T. Kozu, Y. Ohno, K. Nakamura, A. Higuchi, K. M. C. Reddy, V. K. Ananadan, P. Srinivasulu, A. R. Jain, P. B. Rao, R. Ranga Rao, G. Viswanathan and D. Narayana Rao, Radio Sci., 37, doi: 10.1029/2000RS002538, 2002 (*Citations*: 23).
53. Spatial domain interferometric VHF radar observations of spread meteor echoes, C. Raghava Reddi, T. V. C. Sarma and P. B. Rao, J. Atmos. Solar Terr. Phys., 64, Issue 3, 339-347, 2002 (*Citations*: 8).
54. Coordinated MST radar and Lidar observations for the study of mesospheric structures over a tropical station, M. Venkat Ratnam, D. Narayana Rao, M. Krishnaiah, Y. Bhavani Kumar, V. Sivakumar and P. B. Rao, J. Atmos. Solar Terr. Phys., 64, 349-358, 2002 (*Citations*: 20).

2003

55. Atmospheric boundary layer observations over Gadanki using lower atmospheric wind profiler: Preliminary results, Praveena Krishnan, P. K. Kunhikrishnan, S. Muraleedharan Nair, Sudha Ravindran, A. R. Jain, T. Kozu, Curr. Sci., 85, 75-, 2003 (*Citations*: 9).
56. Simultaneous radar observations of the electrojet plasma irregularities at 18 and 54.95 MHz over Trivandrum, India, D. Tiwari, A. K. Patra, K. S. Viswanathan, N. Jyoti, C. V. Devasia, K. S. V. Subbarao and R. Sridharan, J. Geophys. Res., 108, 1368, doi:10.1029/2002JA009698, 2003 (*Citations*: 10).
57. Lidar Measurements of Stratosphere-Mesosphere thermal structure at a low latitude: Comparison with satellite data models, V. Sivakumar, P. B. Rao and M. Krishnaiah, J. Geophys. Res., 108, 2003 (*Citations*: 56).
58. Lidar observations of cirrus cloud near the tropical tropopause:temporal variations and association with tropospheric turbulence, K. Parameswaran, S. V. Sunilkumar, B. V. Krishna Murthy, K. Satheesan, Y. Bhavani Kumar, M. Krishnaiah and Prabha R. Nair, Atmos. Research, 69, 2003 (*Citations*: 17).

59. A study of equatorial wave characteristics using Rockets, Balloons, Lidar and Radar, M. N. Sasi, B. V. Krishna Murthy, Geetha Ramkumar, K. Satheesan, K. Parameswaran, K. Rajeev, S.V. Sunil Kumar, Prabha R. Nair, K. Krishna Moorthy, Y. Bhavani Kumar, K. Raghunath, A. R. Jain, P. B. Rao, M. Krishnaiah, S. R. Prabhakaran Nayar, K. Revathy and S. Devanarayanan., Adv. Space Res., 32, 2003 (*Citations*: 18).
60. Recent observations of mesospheric temperature inversions over a tropical station (13.5^{O}N, 79.2^{O}E), M. Venkat Ratnam, J. B. Nee, W. N. Chen, V. Sivakumar and P. B. Rao, J. Atmos. Solar Terr. Phys., 65, 323-334, 2003 (*Citations*: 14).
61. Shear instability as a source of the daytime quasi-periodic radar echoes observed by the Gadanki VHF radar, S. Sripathi, A. K. Patra, V. Sivakumar and P. B. Rao, Geophys. Res. Lett., 30, 22, 2149, doi:10.1029/2003GL017544, 2003 (*Citations*: 13).
62. Lidar observed characteristics of the tropical cirrus clouds, V. Siva Kumar, Y. Bhavani kumar, P.B. Rao, K.Mizutari, T.Aoki, M. Yasui and T. Itable, Radio Sci., 38, 1094, doi:10.1029/2002 RS002719, 2003 (*Citations*: 13).
63. A simultaneous MST radar and radiosonde measurements at Gadanki (13.5°N, 79.2°E) Part-I: causative mechanism and characteristics of radar backscatters at VHF, A. R. Jain, A. K. Ghosh, V. Sivakumar and K. Kishore Kumar, Radio Sci., 38, 1013, doi:10.1029/2000RS002527, 2003 (*Citations*: 9).
64. A simultaneous MST radar and radiosonde measurements at Gadanki (13.5°N, 79.2°E) Part- II: Determination of various turbulence parameters, A. K. Ghosh, A. R. Jain and V. Sivakumar, Radio Sci., 38, 1014, doi: 10.1029/2000RS002527, 2003 (*Citations*: 9).

2004

65. Lidar observations of middle atmospheric temperature variability over low latitude, M.Krishnaiah, U. Jaya Prakash Raju,Y. Bhavani Kumar, K. Raghunath, V. Siva Kumar and P. B. Rao, Ind J Radio & Space phys., 33, 50-57,2004 (*Citations*: 2).
66. Radar observations of 8.3 m scale equatorial spread F over Trivandrum, D. Tiwari, A. K. Patra, C. V. Devasia, R. Sridharan, N. Jyothi, K. S. Viswanathan and K.S.V. Subbarao, Ann. Geophys., 22, 911-922, 2004 (*Citations*: 6).
67. Aspect sensitivity in the VHF radar backscatters studied using simultaneous observations of Gadanki MST radar and GPS-sonde, A. K. Ghosh, Siddarth Shankar Das, A. K. Patra, D. Narayana Rao and A. R. Jain, Ann. Geophys., 22, 4013-4023, 2004 (*Citations*: 6).
68. Multitaper spectral analysis of atmospheric radar signal, V. K. Anandan, C. J. Pan, T. Rajalakshmi and G. Ramachandra Reddy, Ann. Geophys., 22, 3995-4003, 2004 (*Citations*: 17).
69. Statistical characteristics of VHF radar observations of low latitude E region field-aligned irregularities over Gadanki, A. K. Patra, S. Sripathi, V. Sivakumar and P. B. Rao, J. Atmos. Sol. Terr. Phys., 66, 1615-1626, 2004 (*Citations*: 27).
70. Characterization of VHF radar structures associated with equatorial spread-F by narrow-band optical observations, R. Sekar, D. Chakrabarty, R. Narayanan, S. Sripathi, A. K. Patra and K. S. V. Subbarao, Ann. Geophys, 22, 3129-3136, 2004 (*Citations*: 12).
71. Coupling effect of the equatorial F region irregularities on the low latitude E region instability processes, A. K. Patra, S. Sripathi and D. Tiwari, Geophys. Res. Lett., 31, L17803, doi: 10.1029/2004GL020486, 2004 (*Citations*: 12).

72. Observations of trapped humidity layer and Kelvin-Helmholtz instability using UHF radar and GPS sonde, S. S. Das, K. Kishore Kumar, A. R. Jain, D. Narayana Rao and K. Nakamura, Radio Sci., 39, doi: 10.1029/RS003003, 2004 (*Citations*: 2).

2005

73. Ionospheric irregularities in the low-latitude valley region observed with the Equatorial Atmosphere Rad, T. Yokoyama, A. K. Patra, S. Fukao and M. Yamamoto, J. Geophys. Res., 110, A10304, doi:10.1029/2005JA011208, 2005 (*Citations*: 19).
74. Studies on atmospheric gravity wave activity in the troposphere and lower stratosphereover a tropical station at Gadanki, I. V. Subba Reddy, D. Narayana Rao, A. Narendra Babu, M. Venkat Ratnam, P. Kishore and S. Vijaya Bhaskara Rao, Ann. Geophys, 23, 3237-3260, SRef-ID: 1432-0576/ag/2005-23-3237, 2005 (*Citations*: 6).
75. East- west asymmetries of the equatorial electrojet 8.3m type-2 echoes observed over Trivandrum and a possible explanation, A. K. Patra, D. Tiwari, C. V. Devasia, T. K. Pant and R. Sridharan, J. Geophys Res., 110, A11305, doi:10.1029/2005JA011124, 2005 (*Citations*: 7).
76. On the optimum time of integration for estimation of momentum flux from VHF radar data, Gopa Dutta, P. V. Rao, M.C. Ajay Kumar, P. Vinay Kumar and H. Aleem Basha, V.K. Anandan and A.K. Ghosh, Geophys. Res. Lett., 32, L15811, doi:10.1029/2005 GL023777, 2005 (*Citations*: 4).
77. VHF/UHF radar observations of tropical mesoscale convective systems over southern India, K. Kishore Kumar, A. R. Jain and D. Narayana Rao, Ann. Geophys., 23, 1673-1683, 2005 (*Citations*: 17).
78. Study of equatorial Kelvin waves using the MST radar and Radiosonde observations, P. Kishore, I. V. Subba Reddy, S. P. Namboothiri, K. Igarashi, M. Venkat Ratnam, D. Narayana Rao and S. Vijay Bhaskara Rao, Ann. Geophys., 23, 1123-1130, 2005 (*Citations: Nil*).
79. Disruption of E region echoes observed by the EAR during the development phase of equatorial Spread F: A manifestation of electrostatic field coupling, A. K. Patra, T. Yokoyama, M. Yamamoto, S. Saito, T. Maruyama and S. Fukao, Geophys. Res. Lett., 32, L17104, doi:10.1029/2005GL022868, 2005 (*Citations*: 12).
80. Simultaneous radar observations of meter-scale F region irregularities at and off the magnetic equator over India, A. K. Patra, D. Tiwari, S. Sripathi, P. B. Rao, R. Sridharan, C. V. Devasia, K. S. Viswanathan, K. S. V. Subbarao, R. Sekar and E. A. Kherani, J. Geophys. Res. 110, A02307, doi:10.1029/2004JA010565, 2005 (*Citations*: 13).
81. Simultaneous VHF radar backscatter and ionosonde observations of low latitude E region,A. K. Patra, S. Sripathi, P. B. Rao and K. S. V. Subbarao, Ann. Geophys., 23, 773-779, 2005 (*Citations*: 12).
82. Characteristics of tropopause folds over arctic latitudes, T. N. Rao and S. Kirkwood: J. Geophys. Res., 110, doi:10.1029/2004JD005374, 2005 (*Citations*: 17).
83. Raman lidar observations of height profiles of upper troposphere and lower stratosphere temperature over a tropical site Gadanki, Y. Bhavani Kumar, K. Mizutani, Proc. SPIE, 5653, 59, 298-307, 2005 (*Citations: Nil*).

84. A backscatter lidar observations of lower atmospheric aerosol during daytime over a tropical rural site Gadanki, Y. Bhavani Kumar, K. Mizutani, Proc. SPIE, 5653, 308-318, 2005 (*Citations: Nil*).

2006

85. Effects of interplanetary electric field on the development of an equatorial spread F event, D. Chakrabarthy R.Sekar, R. Narayanan, A. K. Patra and C. V. Devasia, J. Geophys. Res., 111, A12316, doi: 10.1029/ 2006JA011884, 2006 (*Citations*: 24).
86. Radar observations of Leonid meteor shower 2003, D. V. Phanikumar, K. Chenna Reddy and G. Yellaiah, Astrophys. Space Sci., 306, 235-239, 2006 (*Citations*: 2).
87. Indo-Japanese Lidar Observations of the Tropical Middle Atmosphere during 1998 and 1999, Y. Bhavani Kumar, C. Nageswara Raju and M. Krishnaiah, Adv. Atmos. Sci., 23, 711-725, 2006 (*Citations*: 15).
88. Portable lidar system for atmospheric boundary layer measurements, Y. Bhavani Kumar, J. Optical Engineering, 45, 076201, 2006 (*Citations*: 33).
89. Gadanki radar observations of daytime E region echoes and structures extending down to 87 km, A. K. Patra, S. Sripathi, P.B. Rao and R. K. Choudhary, Ann. Geophys, 24, 1861-1869, 2006 (*Citations*: 13).
90. Rayleigh lidar observations of double stratopause structure over three different northern hemisphere stations, V. Sivakumar, H. Bencherif, A. Hauchecorne, P. Keckhut, D. N. Rao, S. Sharma, H. Chandra, A. Jayaraman and P. B. Rao, Atmos. Chem. Phys. Discuss., 6, 6933-6956, 2006 (*Citations*: 9).
91. Planetary wave signatures in the equatorial atmosphere–ionosphere system and mesosphere- E- and F-region coupling, M. A. Abdu, T. K. Ramkumar, I. S. Batista, C. G. M. Brum, H. Takahashi, B. W. Reinisch and J. H. A. Sobral, J. Atmos. Solar Terr. Phys., 68, 509-522, 2006 (*Citations*: 59).
92. Seasonal and diurnal variations of raindrop size distributions in Asian monsoon region, T. Kozu, K. K. Reddy, S. Mori, M. Thurai, J.T. Ong, D. N. Rao and T. Shimomai, Journal of the Meteorological Society of Japan, 84A, 195-209, 2006 (*Citations*: 45).
93. Rayleigh lidar observations of planetary waves in the middle atmosphere over Gadanki (13.5°N, 79.2° E), P. Kishore, S. P. Namboothiri, K. Igarashi, V. Sivakumar, S. Thulasiraman,I. V. Subba Reddy, K. Mizutani, D. Narayana Rao, S. V. B. Rao and Y. Bhavani Kumar, J. Atmos. Solar Terr. Phys., 68, 901-910, doi:10.1016/j.jastp.2006.01.010., 2006 (*Citations*: 11).
94. Observational evidences on the influences of tropical lower atmospheric ~20 day oscillation on the ionospheric equatorial electrojet,T. K. Ramkumar, Y. Bhavanikumar, D. Narayana Rao, S. Gurubaran, A. Narendra Babu, A. K. Ghosh and R. Rajaram, J. Atmos. Solar Terr. Phys., 68, 523-538, doi: 10.1016/j.jastp.2005.03.026, 2006 (*Citations*: 10).
95. Radar observations of daytime 150-km echoes from outside the equatorial electrojet belt over Gadanki, A. K. Patra and N. Venkateswara Rao, Geophys. Res. Lett., 33, L03104, doi: 10.1029/2005GL024564, 2006 (*Citations*: 21).
96. Seasonal variation of gravity waves in the Equatorial Middle Atmosphere: results from ISRO's Middle Atmospheric Dynamics (MIDAS) program, G. Ramkumar, T. M. Antonita,

Y. Bhavani Kumar, H. Venkata Kumar and D. Narayana Rao, Ann. Geophys, 24, 2471–2480, 2006 (*Citations*: 21).

97. On the variability of the shape-slope parameter relations of the gamma raindrop size distribution model, T. N. Rao, N. V. P. Kirankumar, B. Radhakrishna and D. N. Rao, Geophys. Res. Lett., 33, L22809, doi:10.1029/2006GL028440, 2006 (*Citations*: 22).
98. Cirrus observations using ground-based lidar and Terra MODIS instrument, P. Kulkarni, Y.Bhavani Kumar, P. Vishnu Prasanth, D. Narayana Rao and M. Krishniah, Remote Sensing of the Atmosphere and Clouds, Proc. SPIE, 6408, 2006 (*Citations: Nil*).
99. Lidar observations of sporadic Na layers over Gadanki (13.5°N, 79.2°E), P. Vishnu Prasanth, Y. Bhavani Kumar and D. Narayana Rao, Proc. SPIE, 6409, 2006 (*Citations*: 11).

2007

100. Identification of Tropopause using Bending Angle profile from GPS Radio Occultation (RO): A Radio Tropopause, D. Narayana Rao, M. Venkat Ratnam, B. V. Krishna Murthy, V. V. M. Jagannadha Rao, Sanjay Mehta, Debashis Nath and Ghouse Basha , Geophys. Res. Lett., 34, doi:10.1029/2007GL029709, 2007 (*Citations*: 20) .
101. Further investigations on 150-km echoing riddle using simultaneous observations of 150-km and E-region echoes from offelectrojet location Gadanki, A. K. Patra and N. Venkateswara Rao, J. Geophys. Res., 112, A09301, doi:10.1029/2006JA012204, 2007 (*Citations*: 15).
102. Lidar system for mesospheric sodium measurements, Y. Bhavani Kumar, D. N. Rao, M. S. Murthy and M. Krishnaiah, J. Optical Engg., 46, 086203, 2007 (*Citations: Nil*).
103. Lidar observations of sporadic Na layers over Gadanki (13.5°N, 79.2°E), P. Vishnu Prasanth, S. Sridharan, Y. Bhavani Kumar and D. Narayana Rao, Ann. Geophys., 25, 1759-1766, 2007 (*Citations: Nil*).
104. The first lidar observations of the nighttime sodium layer at low latitudes Gadanki (13.5ºN, 79.2ºE), India, Y. Bhavani Kumar, P. V. Prasanth, D. N. Rao, M. S. Murthy and M. Krishnaiah, Earth, Planets Space 59, 601-611, 2007 (*Citations*: 8) .
105. Diurnal and seasonal variability of TKE dissipation rate in the ABL over a tropical station using UHF wind profiler, M. C. R. Kalapureddy, K. Kishore kumar, V. Sivakumar, A.K. Ghosh, A. R. Jain and K. K. Reddy, J. Atmos. Solar Terr. Phys., 69, 419-430, doi:10.1016/j.jastp.2006.10.016, 2007 (*Citations*: 14).
106. Climatology of low-latitude mesospheric echo characteristics observed by Indian mesosphere, stratosphere and troposphere radar, G. Kishore Kumar, M. Venkat Ratnam, A. K. Patra, V. V. M. Jagannadha Rao, S. Vijaya Bhaskara Rao and D. Narayana Rao J. Geophys. Res., 112, d06109, doi : 10.1029/2006jd007609, 2007 (*Citations*: 18).
107. Low-latitude valley region irregularities studied using the Gadanki radar, A. K. Patra and N. Venkateswara Rao, J. Geophys. Res., 112, A03303, doi : 10.1029/2006JA011857, 2007 (*Citations*: 7).
108. VHF radar investigations on the role of mechanical oscillator effect in exciting convectively generated gravity waves, K. K. Kumar, Geophys. Res. Lett., 34, L01803, doi:10.1029/2006GL027404, 2007 (*Citations*: 18).
109. Lower E-region field-aligned irregularities studied using the Equatorial Atmosphere Radar and meteor radar in Indonesia, A. K. Patra, T. Yokoyama, M. Yamamoto, T.

Nakamura, T. Tsuda and S. Fukao, J. Geophys. Res. 112, A01301, doi:10.1029/2006JA011825, 2007 (*Citations*: 17).

110. Anomalous wind circulation observed during 1997/98 El Nino using Indian MST Radar, V. V. M. Jagannadha Rao, A. Narendra Babu, S. VijayaBhaskar Rao and D. Narayana Rao, Journal of Applied Meteorology and Climatology, 46, 112-119, 2007 (*Citations*: 3).
111. Onset of Indian Summer Monsoon over Gadanki (13.5°N; 79.2°E): Study using Lower Atmospheric Wind Profiler (LAWP), V. V. M. Jagannadha Rao, M. Roja Raman, M. VenkatRatnam and D. Narayana Rao, Geophys. Res. Lett., 34, L22803, doi:10.1029/2007GL031592., 2007 (*Citations*: 4).
112. Radar observations of long-term variability of mesosphere and lower thermosphere winds over Tirunelveli (8.7°N, 77.8°E), S. Sridharan, T. Tsuda and S. Gurubaran, J. Geophys. Res., 112, D23105, doi:10.1029/2007JD008669, 2007 (*Citations*: 26).
113. A short review on wind profiler observations of lower and middle atmospheric processes over Gadanki, T. N. Rao and D. N. Rao, Ind. J. Radio & Space Phys., 36, 526-542, 2007 (*Citations*: 2).
114. Developments and achievements in atmospheric sciences and space meteorology in India, A. Jayaraman, P. C. Joshi and R. Ramesh, Curr. Sci. 93, 1779-1790, 2007 (*Citations*: 7).
115. Study of equatorial spread-F using L-band VHF Radar, M. Aggarwal, H. P. Joshi, K. N. Iyer, A. K. Patra and S. V. Thampi, Bull. Astr. Soc. India, 35, 631-637, 2007 (*Citations: Nil*).
116. Identification of active fossil bubbles based on coordinated VHF radar and airglow measurements, R. Sekar, D. Chakrabarty, S. Sarkhel, A. K. Patra, C. V. Devasia and M. C. Kelley, Ann. Geophys., 25, 2099–2102, 2007 (*Citations*: 20).
117. Low-latitude E-region quasi-periodic echoes studied using long-term radar observations over Gadanki, N. Venkateswara Rao, A. K. Patra and S. V. B. Rao, Adv. Geosci. Sol. Terr., 14, 245-261, 2007 (*Citations: Nil*).

2008

118. Some aspects of electrostatic coupling between E and F regions relevant to plasma irregularities: A review based on recent observations, A.K. Patra, J. Atmos. Sol. Terr. Phys, doi:10.1016/j.jastp.2008 (*Citations*: 4).
119. Seasonal variation of low-latitude E-region plasma irregularities studied using Gadanki radar and ionosonde, D. V. Phanikumar, A. K. Patra, C. V. Devasia and G. Yellaiah, Ann. Geophys., 26, 1865–1876, 2008 (*Citations*: 5).
120. Daytime 150-km echoes observed with the Equatorial Atmosphere Radar in Indonesia: First results, A. K. Patra, T. Yokoyama, Y. Otsuka and M. Yamamoto, Geophys. Res. Lett., 35, doi:10.1029/2007GL033130, 2008 (*Citations*: 15).
121. Morphological and seasonal characteristics of low-latitude E-region quasi-periodic echoes studied large database of Gadanki observations, N. Venkateswara Rao, A. K. Patra, T. K. Pant and S. V. B. Rao, J. Geophys. Res., 113, 26, doi:10.1029/ 2007JA012830, 2008 (*Citations*: 4).
122. Some new aspects of low-latitude E-region QP echoes revealed by Gadanki radar: Are they due to Kelvin-Helmholtz instability or gravity waves? N. Venkateswara Rao, A. K. Patra and S. V. B. Rao, J. Geophys. Res., 113, A03309, 2007JA012574, 2008 (*Citations*: 17).

123. VHF Radar echoes in the vicinity of tropopause during the passage of tropical cyclone: First observations from the Gadanki MST radar, S. S. Das, A. K. Patra and D. N. Rao, J. Geophys. Res., 2007JD009014, 2008 (*Citations*: 10).
124. Geminid meteor shower activity as observed by Gadanki radar, K. Chenna Reddy, D. V. Phani Kumar and G. Yellaiah, Planet. Space Sci., 56, 1014-1022, 2008 (*Citations: Nil*).
125. MST radar and radiosonde observations of inertia-gravity wave climatology over tropical stations: Source mechanisms, M. VenkatRatnam, A. Narendra Babu, V. V. M. Jagannadha Rao, S. VijayaBhaskar Rao and D. Narayana Rao, J. Geophy. Res., 113, D07109, doi: 10.1029/2007JD008986, 2008 (*Citations*: 27).
126. Long-term MST radar observations of vertical wave number spectra of gravity waves in the tropical troposphere over Gadanki (13.5°N, 79.2°E): comparison with model spectra, Narendra Babu, K. Kishore Kumar, G. Kishore Kumar, M. VenkatRatnam, S. VijayaBhaskara Rao and D. Narayana Rao, Ann. Geophys., 26, 1671–1680, 2008 (*Citations*: 1).
127. Evaluation of DBS wind measurement technique in different beam combinations for UHF/VHF wind profilers, I. Srinivasa Rao, V.K.Anandan and P.Narasimha Reddy, J. Atmos. Ocean. Tech., DOI:10./2008JTECHA1133.1, 2008 (*Citations*: 14).
128. A study on optimum tilt angle for wind measurements using Indian MST Radar, V.K.Anandan, I. Srinivasa Rao and P.Narasimha Reddy, J. Atmos.Ocean. Tech., DOI:10.1175/2008JTECHA1030.1, 2008 (*Citations*: 4).
129. First results of experimental tests of newly developed NARL phased array Doppler SODAR, V. K. Anandan, M. Shravan Kumar, I. Srinivasa Rao, J. Atmos.Oce.Tech. doi:10.1175/2008JTECHA1050.1, 2008 (*Citations*: 15).
130. The 5-8-day Kelvin and Rossby waves in the tropics as revealed by ground and satellite-based observations, S. Sridharan, T. Tsuda, T. Nakamura and T. Horinouchi, J. Meteor. Soc. Jpn., 86, 43-55, 2008 (*Citations*: 5).
131. Characteristics of inertia-gravity waves over Gadanki during the passage of a deep depression over the Bay of Bengal, K. Niranjan Kumar and T. K. Ramkumar, Geophys. Res. Lett., 35, L13804, doi:10.1029/2008GL033937, 2008 (*Citations*: 6).
132. Validation of MODIS derived Aerosol Optical Depth over Western India, A. Misra, A. Jayaraman and D. Ganguly, J Geophys. Res., 113, D04203, doi:10.1029/ 2007JD009075, 2008 (*Citations*: 45).
133. Fog-induced variations in aerosol optical and physical properties over the Indo-Gangetic Basin and impact to aerosol radiative forcing, S. K. Das, A. Jayaraman and A. Misra, Ann. Geophys., 26, 1345–1354, 2008 (*Citations*: 35).
134. Inferring microphysical processes occurring in mesoscale convective systems from radar measurements and isotopic analysis, T. N. Rao, B. Radhakrishna, Rohit Srivastava, T. Mohan Satyanarayana, D. N Rao and R. Ramesh, Geophys. Res. Lett., 35, L09813, doi:10.1029/2008GL033495, 2008 (*Citations*: 10).
135. Classification of tropical precipitating systems using wind profiler spectral moments. Part I: Algorithm description and validation, T. N. Rao, N.V.P. Kirankumar, B. Radhakrishna, D. N. Rao and K. Nakamura, J. Atmos. Ocean. Tech., 25, 884-897, 2008 (*Citations*: 22).
136. Classification of tropical precipitating systems using wind profiler spectral moments. Part II: Statistical characteristics of rainfall systems and sensitivity analysis, T. N. Rao, N.V.P. Kirankumar, B. Radhakrishna, D. N. Rao and K. Nakamura, J. Atmos. Ocean. Tech., 25, 898-908, 2008 (*Citations*: 7).

137. Statistical characteristics of raindrop size distribution in southwest monsoon season, N. V. B. Kirankumar, T. N. Rao, B. Radhakrishna, D. N. Rao, J. Appl. Meteorol. Climatol., 47, 576 – 590, 2008 (*Citations*: 18).
138. Climatology of tropopause folds over a European Arctic station – ESRANGE, T. N> RaoRao, T. N., J. Arvelius and S. Kirkwood, J. Geophys. Res., 113, D00B03, doi:10.1029/2007JD009638, 2008 (*Citations*: 15).
139. Understanding the transportation process of tropospheric air entering the stratosphere from direct vertical air motion measurements over Gadanki and Kototabang, Rao, T.N., K. N. Uma, D. N. Rao and S. Fukao,Geophys. Res. Lett., 35, L15805, doi:10.1029/2008GL034220, 2008 (*Citations*: 12).
140. Identification of tropical convective tropopause and its association with cold point tropopause, S. K. Mehta, B. V. Krishna Murthy, D. Narayana Rao, M. VenkatRatnam, K. Parameswaran, K. Rajeev, C. Suresh Raju and Kusuma G. Rao, J Geophys. Res., 113, D00B04, doi:10.1029/2007JD009625, 2008 (*Citations*: 17).
141. First results from the CAWSES-India Tidal Campaign, S. Gurubaran, D. Narayana Rao, G. Ramkumar, T. K. Ramkumar, G. Dutta and B. V. Krishna Murthy, Ann. Geophys., 26, 2323–2331, 2008 (*Citations*: 6).
142. Simultaneous observations of ESF irregularities over Indian region using radar and GPS, S. Sripathi, S. Bose, A. K. Patra, T. K. Pant, B. Kakad and A. Bhattacharyya, Ann. Geophys., 26, 3197–3213, 2008 (*Citations*: 14).
143. Equatorial Spread F structures and associated airglow intensity variations observed over Gadanki, R. Sekar, D. Chakrabarty, R. Narayanan and A. K. Patra, Ann. Geophys., 26, 3863–3873, 2008 (*Citations*: 5).
144. Low-latitude mesospheric mean winds observed by Gadanki mesosphere stratosphere troposphere (MST) radar and comparison with rocket, High Resolution Doppler Imager (HRDI) and MF radar measurements and HWM93, G. Kishore Kumar, M. Venkat Ratnam, A. K. Patra, V. V. M. Jagannadha Rao, S. Vijaya Bhaskar Rao, K. Kishore Kumar, S. Gurubaran, G. Ramkumar and D. Narayana Rao, J. Geophys. Res., 113, D19117, doi:10.1029/2008JD009862, 2008 (*Citations*: 11).
145. Long-term variability of the low latitude mesospheric SAO and QBO and their relation with stratospheric QBO, M. V. Ratnam, G. K. Kumar, B. V. K. Murthy, A. K. Patra, V. V. M. J. Rao, S. V. B. Rao, K. K. Kumar and G. Ramkumar, Geophys. Res. Lett., 35, L21809, doi:10.1029/2008GL035390, 2008 (*Citations*: 20).
146. Mean thermal structure of the low-latitude middle atmosphere studied using Gadanki Rayleigh lidar, Rocket and SABER/TIMED observations, G. Kishore Kumar, M. VenkatRatnam, A. K. Patra, S. VijayaBhaskara Rao and J. Russell, J. Geophys. Res., 113, D23106, doi:10.1029/2008JD010511, 2008 (*Citations*: 26).
147. First mesospheric turbulence study using coordinated rocket and MST radar measurements over Indian low latitude region, H. Chandra, H. S. S. Sinha, U. Das, R. N. Misra, S. R. Das, J. Datta, S. C. Chakravarty, A. K. Patra, N. Venkateswara Rao and D. Narayana Rao, Ann. Geophys., 26, 2725–2738, 2008 (*Citations*: 12).
148. Seasonal and interannual variations of gravity wave activity in the low-latitude mesosphere and lower thermosphere over Tirunelveli (8.7° N, 77.8° E), Sridharan .S. and S. Sathishkumar, Ann. Geophys., 26, 3215-3223, 2008 (*Citations*: 11).
149. Influence of gravity waves and tides on mesospheric temperature inversion layers: simultaneous Rayleigh lidar and MF radar observations, Sridharan, S., S. Sathishkumar and S. Gurubaran, Ann. Geophys., 26, 3731–3739, 2008 (*Citations*: 6).

150. Summer-time nocturnal wave characteristics in mesospheric OH and O2 airglow emissions, Guharay, A. Taori and M. Taylor, Earth Planet Space, 60, 973-979, 2008 (*Citations*: 17).
151. A report on long-term trends and variabilities in middle atmospheric temperature over Gadanki (13.5°N, 79.2°E). Sridharan, S., P. Vishnu Prasanth and Y. Bhavani Kumar, J. Atmos. Sol.Terr. Phy., doi:10.1016/ j.jastp.2008.09.017, 2008 (*Citations*: 13).
152. Atmospheric Circulation during Active and Break Phases of Indian Summer Monsoon: A Study using MST Radar at Gadanki (13.5°N, 79.2°E), M. Roja Raman, V.V.M. Jagannadha Rao, M. VenkatRatnam, G. Kishore Kumar, A. Narendra Babu, S. VijayaBhaskara Rao, N. Prabhakara Rao and D. Narayana Rao, J. Geophys. Res., 113, D20124, doi:10.1029/2008JD010341, 2008 (*Citations*: 3).
153. Analysis of variability and trends of extreme rainfall events over India using 104 years of gridded daily rainfall data, M Rajeevan, JyotiBhate and A.K.Jaswal, Geophys. Res. Lett., 2008, 35, L18707, doi 10.1029/2008GL035143, 2008 (*Citations*: 112).
154. Inter-annual relationship between Atlantic sea surface temperature anomalies and Indian summer monsoon, M. Rajeevan and L. Sridhar, Geophys. Res. Lett., doi 10.1029/2008GL036025., 2008 (*Citations*: 21).
155. Out of phase relationships between convection over northwest India and warm pool region during the winter season, R.K.Yadav, K.Rupa Kumar and M.Rajeevan, Int. J. Climatol., DOI 10.1002/joc.1783, 2008 (*Citations*: 11).
156. Climate change scenarios for northwest India winter season, R.K.Yadav, K.Rupa Kumar and M. Rajeevan, Quater. Inter., DOI 10.1016/ quaint.20.08.09.012, 2008 (*Citations*: 10).
157. Estimates of surface ultraviolet radiation over North America using Geostationary Operational Environmental Satellites observations, H. Gadhavi, R. T. Pinker and I. Laszlo, J. Geophy. Res., 112, D21205, doi: 10.1029/2007JD009308, 2008 (*Citations*: 10).
158. Development of radio acoustic sounding system (RASS) with Gadanki MST radar – first results, T. V. Chandrasekhar Sarma, D. Narayana Rao, J. Furumoto and T. Tsuda, Ann. Geophys.,.26, 2531-2542, 2008 (*Citations*: 6) .
159. Features of upper troposphere and lower stratosphere aerosols observed by lidar over Gadanki, a tropical Indian station, P. Kulkarni, S. Ramachandran, Y. Bhavani Kumar, D. Narayana Rao, Krishnaiah, J. Geophys. Res. doi:10.1029/2007JD009411, 2008 (*Citations*:13).

2009

160. Solar eclipse-induced E-region plasma irregularities observed by the Gadanki radar, A. K. Patra, R. K. Choudhary and J.-P. St.-Maurice, Geophys. Res. Lett., 36, L13105, doi:10.1029/2009GL038669, 2009 (*Citations*: 8).
161. Low-altitude quasi-periodic echoes studied using a large database of Gadanki radar observations, N. Venkateswara Rao, A. K. Patra and S. V. B. Rao, J. Geophys. Res., 114, A01313, doi:10.1029/2008JA013397, 2009 (*Citations*: 2).
162. Planetary scale variability in the low-latitude E region field-aligned irregularities: First results from Gadanki observations, D. V. Phanikumar, A. K. Patra, M. V. Ratnam and S. Sripathi, J. Geophys. Res., 114, A01301, doi:10.1029/ 2008JA013564, 2009 (*Citations*: 2).

163. Zonal asymmetry of daytime 150-km echoes observed by Equatorial Atmosphere Radar in Indonesia, T. Yokoyama, D. L. Hysell, A. K. Patra, Y. Otsuka and M. Yamamoto, Ann. Geophys., 27, 967–974, 2009 (*Citations*: 7).
164. Daytime low-altitude quasi-periodic echoes at Gadanki: understanding of their generation mechanism in the light of their Doppler characteristics, A. K. Patra, N. Venkateswara Rao and R. K. Choudhary, Geophys. Res. Lett., 36, L05107, doi:10.1029/ 2008GL036670, 2009 (*Citations*: 3).
165. Mesospheric planetary wave signatures in the equatorial electrojet,T. K. Ramkumar, S. Gurubaran and R. Rajaram, J. Geophy. Res., 114, A03309, doi:10.1029/2007JA012935, 2009 (*Citations*: 6).
166. Observations of peculiar sporadic sodium structures and their relation with wind variations, Sridharan, S., P. Vishnu Prasanth, Y. Bhavani Kumar, GeethaRamkumar, S. Sathishkumar, K. Raghunath, J. Atmos. Sol.Terr. Phy., 575- 582. 2009 (*Citations*: 5).
167. Rayleigh lidar observations of enhanced statopause temperature over Gadanki (13.5°N, 79.2°E) during major stratospheric warming in 2006, Sridharan, S., S. Sathishkumar and K. Raghunath, Ann. Geophys., 27, 373-379. 2009 (*Citations*: 5).
168. Validation of the COSMIC Radio Occultation data over Gadanki (13.48oN, 79.2oE): A tropical region, D. Narayana Rao, M. VenkatRatnam, Sanjay Mehta, DebashisNath and GhouseBasha, V. V. M. Jagannadha Rao, B. V. Krishna Murthy, T. Tsuda and Kenji Nakamura, Terr. Atmos. Ocean. J., 20, 59-70, doi: 10.3319/ TAO.2008.01.23.01(F3C), 2009 (*Citations*: 23).
169. Gravity wave characteristics observed over a tropical station using high-resolution GPS radiosonde soundings, D. Nath, M. VenkatRatnam, V. V. M. Jagannadha Rao, B. V. Krishna Murthy and S. VijayaBhaskara Rao, J. Geophys. Res., 114, D06117, doi:10.1029/2008JD011056, 2009 (*Citations*: 34).
170. Comparison of the NCEP/NCAR Reanalysis II winds with those observed over a complex terrain in lower atmospheric boundary layer, M. Shravan Kumar and V. K. Anandan, Geophys. Res. Lett., 36, L01805, doi:10.1029/2008GL036246, 2009 (*Citations*: 5).
171. Multifrequency Decoding of a Phased Array Doppler Sodar, I. Srinivasa Rao, V. K. Anandan and M. Shravan Kumar, J. Atmos. Ocean. Tech., doi: 10.1175/2008, 26, 759-768, 2009 (*Citations*: 3).
172. An integrated analysis of lidar observations in association with optical properties of aerosols from a high altitude location in central Himalayas , P. Hegde, P. Pant and Y. Bhavani Kumar, Atmos. Sci. Lett., 10, 48-57, 2009 (*Citations*: 16).
173. Spatial and seasonal variability of raindrop size distributions in Southeast India, Radhakrishna, B., T. N. Rao, D. N. Rao, N. P. Rao, K. Nakamura and A. K. Sharma, India, J. Geophys. Res., 114, D04203, doi:10.1029/2008JD011226, 2009 (*Citations*: 12).
174. Characteristics of vertical velocity cores in different convective systems observed over Gadanki, India, Uma, K. N. and T. N. Rao, Mon. Wea. Rev., 137, 954-975, 2009 (*Citations*: 25).
175. Multi-Peak raindrop size distribution observed by UHF/VHF wind profilers during the passage of a mesoscale convective system, Radhakrishna, B. and T. N. Rao, Mon. Wea. Rev., 137, 976-990, 2009 (*Citations*: 4).
176. Analysis of variations of cloud and aerosol properties associated with active and break spells of Indian summer monsoon using MODIS data, Ravi Kiran, V., M. Rajeevan, S. VijayaBhaskara Rao and N Prabhakara Rao, Geophys. Res. Lett., Vol 36, DOI 10.1029/2008GL037135, 2009 (*Citations*: 23).

177. Summer monsoon onset over Kerala: New Definition and prediction, D. S. Pai, D.S. and M. Rajeevan, J. Earth System. Science, 118, 123-135, 2009 (*Citations*: 35).
178. A high resolution daily gridded rainfall dataset (1971-2005) for mesoscale meteorological studies, M. Rajeevan and Jyoti Bhate, 2009, Curr. Sci., 96, 558-562., 2009 (*Citations*: 93).
179. Gadanki radar observations of F region field-aligned irregularities during June solstice of solar minimum: First results and preliminary analysis, A. K. Patra, D. V. Phanikumar and T. K. Pant, J. Geophys. Res., 114, A12305, doi:10.1029/2009JA014437, 2009 (*Citations*: 19).
180. A study on the low-latitude daytime E region plasma irregularities using coordinated VHF radar, rocket-borne and ionosonde observations, A. K. Patra, N. Venkateswara Rao, D. V. Phanikumar, H. Chandra, U. Das, H. S. S. Sinha, T. K. Pant and S. Sripathi, J. Geophys. Res., 114, A11301, doi:10.1029/ 2009JA014501, 2009 (*Citations*: 8).
181. Intriguing aspects of F-region plasma irregularities revealed by the Gadanki radar observations during the SAFAR campaign, A. K. Patra and D. V. Phanikumar, Ann. Geophys., 27, 3781–3790, 2009 (*Citations*: 9).
182. Low latitude E-region irregularities studied using Gadanki radar, ionosonde and in situ measured electron density, D.V. Phanikumar, A.K. Patra, Y.-S. Kwak, K.-H. Kim, G.Yellaiah, Astrophys. Space Sci., 323, 225–233, DOI 10.1007/s10509-009-0066-y, 2009 (*Citations*: 2).
183. First ground-based mesospheric measurements from central Himalayas, A. Guharay, A. Taori, S. Bhattacharjee, P. Pant, B. Pande and K. Pandey, Curr. Sci., 97, 5, 664- 669, 2009 (*Citations*: 5).
184. Large enhancements in low latitude total electron content during 15 May 2005 geomagnetic storm in Indian zone, Dashora, N., S. Sharma, R. S. Dabas, S. Alex and R. Pandey, Ann. Geophys., 27, 5, 1803-1820, 2009 (*Citations*: 28).
185. Dynamical response of low-latitude middle atmosphere to major sudden stratospheric warming events, S. Sathishkumar, S. Sridharan, Ch. Jacobi, J. Atmos. Sol.Terr. Phys., 71, 857–865, 2009 (*Citations*: 13).
186. Planetary and gravity waves in the mesosphere and lower thermosphere region over Tirunelveli (8.7° N, 77.8°E) during stratospheric warming events, S. Sathishkumar and S. Sridharan, Geophys. Res. Lett., 36, L07806, doi:10.1029/ 2008GL037081, 2009 (*Citations*: 24).
187. Lidar observations of sodium layer over low latitude, Gadanki (13.5° N, 79.2° E): seasonal and nocturnal variations, P. Vishnu Prasanth, V. Sivakumar, S. Sridharan, Y. Bhavani Kumar, H. Bencherif and D. Narayana Rao, Ann. Geophy., 27, 3811-3823, 2009 (*Citations*: 3).
188. First simultaneous lidar observations of sodium layers and VHF radar observations of Eregion field-aligned irregularities at the low-latitude station Gadanki, S. Sridharan, A. K. Patra, N. Venkateswara Rao and G. Ramkumar, Ann. Geophys., 27, 3411–3419, 2009 (*Citations*: 2).
189. Longitudinal variability in intraseasonal oscillation in the tropical mesosphere and lower thermosphere region, R. K. Rao, S. Gurubaran, S. Sathishkumar, S. Sridharan, et al., J. Geophys. Res., 114, D19110, doi:10.1029/2009JD011811, 2009 (*Citations*: 8).
190. Simultaneous sodium airglow and lidar measurements over India: a case study, S. Sarkhel, R. Sekar, D. Chakrabarty, R. Narayanan and S. Sridharan, J. Geophys. Res., 114, A10317, doi:10.1029/2009JA014379, 2009 (*Citations*: 8).

191. Variabilities of mesospheric tides and equatorial electrojet strength during major stratospheric warming events, S. Sridharan, S., S. Sathishkumar and S. Gurubaran, Ann. Geophys., 27, 4125–4130, 2009 (*Citations*: 51).
192. Temporal and Spatial Distributions of Atmospheric Wave Energy in the Equatorial Stratosphere Revealed by GPS Radio Occultation Temperature Data obtained with the CHAMP Satellite during 2001-2006, Toshitaka Tsuda, M. Venkat Ratnam, Simon P. Alexander, Toshiaki Kozu and Yukari Takayabu, Earth Planets Space, 61, 525–533, 2009 (*Citations*: 12).
193. Identification of Atmospheric Boundary Layer (ABL) height over a tropical station using high resolution radiosonde refractivity profiles: Comparison with GPS Radio Occultation (RO) measurements, Ghouse Basha and M. Venkat Ratnam, J. Geophys. Res., 114, D16101, doi:10.1029/2008JD011692, 2009 (*Citations*: 43).
194. Characteristics of high frequency gravity waves generated by tropical deep convection: Case studies, Gopa Dutta, P. Vinay Kumar, M.C. Ajay Kumar, M. Venkat Ratnam, M. Chandrashekar, Y. Shibagaki and H. A. Basha, J. Geophys. Res., 114, D18109, doi:10.1029/2008JD011332, 2009 (*Citations*: 8).
195. Characteristics of gravity waves observed with intensive radiosonde campaign during November-December 2005 over western Sumatera, M. Venkat Ratnam, Simon P. Alexander, T. Kozu and T. Tsuda, Earth Planets Space, 61, 2009 (*Citations*: 4).
196. Characteristics of the Tropical Easterly Jet: Long-term trends and their features during active and break monsoon phases, M. Roja Raman, V. V. M. Jagannadha Rao, M. Venkat Ratnam, M. Rajeevan, S. V. B. Rao, D. Narayana Rao and N. Prabhakara Rao, J. Geophys. Res., 114, D19105, doi:10.1029/ 2009JD012065, 2009 (*Citations*: 14).
197. Differences in Raindrop Size Distribution from Southwest Monsoon to Northeast Monsoon at Gadanki, Rao, T. N., B. Radhakrishna, K. Nakamura and N. P. Rao, Quart. J. Royal Meteorol. Soc. 135, 1630-1637, 2009 (*Citations*: 21).
198. Statistical characteristics of multi-peak raindrop size distribution at surface and aloft in different rain regimes, B. Radhakrishna and T. N. Rao, Mon. Wea. Rev., 137, 3501-3518, 2009 (*Citations*: 3).
199. Differences in draft core statistics from wet spell to dry spell over Gadanki (13.5 N, 79.2 E), T. N. Rao, K. N. Uma, T. M. Satyanarayana and D. N. Rao, India, Mon. Wea. Rev., 137, 4293–4306, 2009 (*Citations*: 14).
200. Diurnal variation in vertical air motion over a tropical station, Gadanki (13.5 N, 79.2 E) and its effect on the estimation of mean vertical air motion, K. N. Uma and T. N. Rao, J. Geophys. Res., 114, D20106, doi:10.1029/2009JD012560, 2009 (*Citations*: 4).
201. Turbulence associated with mountain waves over Northern Scandinavia – a case study using the ESRAD VHF radar and the WRF mesoscale model, S. Kirkwood, M. Mihalikova, T. N. Rao and K. Satheesan, Atmos. Chem. Phys. Discuss., 9, 20775-20817, 2009 (*Citations*: 19).
202. Development of a high resolution daily gridded temperature data set (1969-2005) for the Indian region, A.K. Srivastava, M.Rajeevan and S.R.Kshirsagar, Atmos. Sci. Lett., DOI 10.1002/asl.232, 2009 (*Citations*: 48).
203. Improving Global Model Precipitation Forecasts over India from Downscaling and FSU Superensemble Part I- 1-5 days forecasts, T.N. Krishnamurti, A.K., Mishra, A., Chakraborty and M Rajeevan, Mon. Wea. Rev., 137, 2713-2735, 2009 (*Citations*: 23).

204. Variability of extreme rainfall events over India during the southwest monsoon season, D.R. Pattanaik., M Rajeevan, Meteorol. Appl., DOI 10.1002/met.164, 2009 (*Citations*: 23).
205. Daily Indian Precipitation analysis formed from a merge of Rain-Gauge data with the TRMM TMPA satellite-derived rainfall estimates, A.K. Mitra, A.K. Bohra, M.Rajeevan and T.N.Krishnamurti, J.Meteor. Soc. Jpn., 87A, 265-279, 2009 (*Citations*: 45).
206. Impact of MJO on the intraseasonal variation of summer monsoon rainfall over India, D. S. Pai, Jyoti Bhate, O. P. Sreejith, H. R. Hatwar, 2009, Cli. Dyn., DOI 10.1007/s00382-009-0634-4, 2009 (*Citations*: 40).

2010

207. Study of Atmospheric Forcing and Responses (SAFAR) campaign: Overview, A. Jayaraman, M. Venkat Ratnam, A. K. Patra, T. Narayana Rao, S. Sridharan, M. Rajeevan, H. Gadhavi, A. P. Kesarkar, P. Srinivasulu and K. Raghunath, Ann. Geophys., 28, 89–101, 2010 (*Citations*: 17) .
208. Sensitivity of WRF cloud microphysics to simulations of a severe thunderstorm event observed over Southeast India, M.Rajeevan, Amit Kesarkar, S.D.Thampi, T.N.Rao and B.Radhakrishna, 2010, Ann. Geophys, 28, 603-619, 2010 (*Citations*: 44).
209. Absorbing aerosols: contribution of biomass burning and implications for radiative forcing, H. Gadhavi and A. Jayaraman, Ann. Geophys., 28, 103-111, 2010 (*Citations*: 39)
210. The exchange across the tropical tropopause in overshooting convective cores, Rao, T. N., B. Radhakrishna, T. M. Satyanarayana and S. Satheesh Kumar, Ann. Geophys., 28, 113-122, 2010 (*Citations*: 5.
211. Active and break spells of the Indian summer monsoon, M. Rajeevan, Sulochana Gadgil and Jyoti Bhate, J. Earth Sys. Sci., 119, 3, 222-241, 2010 (*Citations*: 131).
212. Turbulence characteristics over tropical station Gadanki (13.5°N, 79.2°E) estimated using high-resolution GPS radiosonde data, D. Nath, M. Venkat Ratnam, A. K. Patra, B. V. Krishna Murthy and S. V. Bhaskar Rao, J. Geophys. Res., 115, D07102, doi:10.1029/2009JD012347, 2010 (*Citations*: 11).
213. Tropical mesopause: Is it always close to 100 km?. M Venkat Ratnam, A. K. Patra and B. V. Krishna Murthy, J. Geophys. Res., 115, D06106, doi:10.1029/2009JD012531, 2010 (*Citations*: 17).
214. Mesospheric Wave Signatures and Equatorial Plasma Bubbles: A Case Study, A. Taori, J.J. Makela and M. Taylor, J. Geophys. Res., 115, doi:10.1029/ 2009JA015088, 2010 (*Citations*: 17).
215. Comparison study of zonal drift velocities measurements as seen by MF spaced antenna and HF Doppler radar in the Indian dip equatorial mesospheric and lower thermospheric (80–100 km) region, T. K. Ramkumar, S. Gurubaran, R. Rajaram, D. Tiwari and K. S. Viswanathan, A., J. Geophys. Res. 115, A02306, doi:10.1029/2009JA014728, 2010 (*Citations: Nil*).
216. Laser radar characterization of atmospheric aerosols in the troposphere and stratosphere using range dependent lidar ratio, M., Satyanarayana, S.R., Radhakrishnan V. P. Mahadevan Pillai, S. Veerabuthiran, B. M. V. Presennakumar and K. Reghunath, J. Appl. Remote Sens., 4, 043503, 2010 (*Citations: Nil*).

217. Dominant winter-time mesospheric wave signatures over a low latitude station, Hawaii (20.8o N): An investigation, A. Taori and M. Taylor, Journal of Earth System, Science, 119, 3, 259-264, doi: 10.1007/s12040-010-0020-y, 2010 (*Citations*: 8).
218. Variations in low – latitude middle atmospheric thermal structure during the 15 January 2010 solar eclipse, A. Taori, S. Sathishkumar and S. Gurubaran, Curr. Sci., 99, 11, 1578-1581, 2010 (*Citations: Nil*).
219. Study of solar activities through upper atmospheric emissions using a mesosphere lowerthermosphere photometer (MLTP) designed at ARIES, T. Bangia, S. Bhattacharjee,A. Guharay, A. Taori and W. Uddin, Ind. J. Radio & SpacePhys., 39, 325-329, 2010 (*Citations*: 2).
220. Ionospheric Response to the Space Weather Event of 18 November 2003 - An Investigation,Pankaj Kumar, Wahab Uddin, AlokTaori, Ramesh Chandra and SuchiBisht, Ind. J. Radio & Space Phys., 39, 290-295, 2010 (*Citations*: 1).
221. Characteristics of atmospheric waves in the upper troposphere observed with the Gadanki MST Radar—RASS, T.V. Chandrasekhar Sarma, Y.-M. Kodama and T. Tsuda, J. Atmos. Sol. Terr. Phys., 2010 (*Citations*: 2).
222. Characterization of low latitude GPS-TEC during very low solar activity phase, P. Galav, N. Dashora, S. Sharma and R. Pandey, J. Atmos. Sol. Terr. Phys., 72, 1309–1317, 2010 (*Citations*: 28).
223. Total solar eclipse of July 22, 2009: Its impact on the total electron content and ionosphericelectron density in the Indian zone, S. Sharma, N. Dashora, P. Galav and R. Pandey, J. Atmos. Sol. Terr. Phys., 72, 1387–1392, 2010 (*Citations*: 8).
224. Nighttime-like quasi periodic echoes induced by a partial solar eclipse, S. V. Thampi, M.Yamamoto, H. Liu, S. Saito, Y. Otsuka and A. K. Patra, Geophys. Res. Lett., 37, L09107,doi:10.1029/ 2010GL042855, 2010 (*Citations*: 6).
225. First results of warm mesospheric temperature over Gadanki (13.51°N, 79.21°E) during the sudden stratospheric warming of 2009, S. Sridharan, K. Raghunath, S. Satheeshkumar and D. Nath, J. Atmos. Sol. Terr. Phys., 72, 1067-1146, 2010 (*Citations*: 13).
226. Optical properties of cirrus clouds at a tropical Indian station Gadanki, Tirupati (13.5°N,79.2°E), S. R. Radhakrishnan, M. Satyanarayana, V. Krishnakumar,V.P. Mahadevan Pillai, Karnam Raghunath, M. VenkataRatnam and D. R. Rao, J. Appl. Remote Sens, J. Appl. Remote Sens., 4,043559, 2010 (*Citations: Nil*).
227. Mie lidar and radiosonde observations at Gadanki (13.5°N, 79.2°E) during sudden stratospheric warming of 2009, S. Sridharan, K. Raghunath, S. Satheeshkumar and D. Nath,J. Atmos. Sol.Terr. Phy., 73, 544-550, 2010, 2010 (*Citations*: 3).
228. State of the Climate in 2009: South Asian Climate, M. Rajeevan, A. K. Srivastava and J. Revadekar, Bull. Amer. Met. Soc., 91, doi: 10.1175/BAMS-91-7- State of the Climate, 2010 (*Citations: Nil*).
229. Fresnel scatter revisited – comparison of 50 MHz radar and radiosondes in the Arctic, the Tropics and Antarctica, S. Kirkwood, E. Belova, K. Satheesan, T. Narayana Rao,T. Rajendra Prasad and S. Satheesh Kumar. Ann. Geophys., 28, 1993-2005, doi:10.5194/angeo-28-1993-2010, 2010 (*Citations*: 14).
230. Design of Control and Interlocking System for a Typical Radar Transmitter. K. Nagabhushan Raju, K. Nagabhushana, C. Manikumar, T. Rajendra Prasad, Sensors & Transducers J., 118, 7, 131-135, 2010 (*Citations: Nil*).

231. Variability of the Tropical Tropopause over Indian Monsoon Region, Sanjay Kumar Mehta, M. VenkatRatnam and B.V. Krishna Murthy, J. Geophy. Res., 115,D14120, doi:10.1029/2009JD012655, 2010 (*Citations*: 11).
232. Global distribution of Atmospheric Boundary Layer (ABL) height using COSMIC GPS RO measurements: Robust method, M. VenkatRatnam and Ghouse Basha, Atmos. Sci. Lett., 11: 216–222, DOI: 10.1002/asl.277, 2010 (*Citations: Nil*).
233. Investigation of gravity waves in the tropical lower atmosphere using radiosonde observations, A. Guharay, M. VenkatRatnam, D. Nath and Umesh Dumka, Radio Sci., 45, RS6008, doi:10.1029/2010RS004372, 2010 (*Citations: Nil*).
234. Effect of the annular solar eclipse of 15 January 2010 on the lower atmospheric boundary layer over a tropical rural station, M. Venkat Ratnam, M. Shravan Kumar, GhouseBasha, V.K. Anandan, A. Jayaraman, J. Atmos. Sol.Terr. Phy., doi:10.1016 /j.jastp. 2010.10.009, 2010 (*Citations*: 13).
235. Long-term tendencies in the mesosphere/lower thermosphere mean winds and tides asobserved by medium frequency radar at Tirunelveli (8.7°N, 77.8°E), S. Sridharan, T. Tsuda,and S. Gurubaran, J. Geophy. Res., 115, D08109,doi:10.1029/2008JD011609, 2010 (*Citations*: 14).
236. First results of convectively generated long-period Kelvin waves in the low-latitud emesosphere during Indian summer monsoon, G. J. Bhagavathiammal, S. Sathishkumar, S. Sridharan, Manohar Lal, S. Gurubaran, K.U. Nair, J. Atmos. Sol.Terr. Phys., 1204-1211, 2010 (*Citations: Nil*).
237. A case study on the possible altitude-dependent effects of collisions on sodium airglow emission, S. Sarkhel, R. Sekar, D. Chakrabarty and S. Sridharan, J. Geophys. Res., 115, A10306, doi:10.1029/2010JA015251, 2010 (*Citations*: 4).
238. Mesosphere stratosphere troposphere radar observations of characteristics of loweratmospheric high frequency gravity waves passing through the tropical easterly jet, T. K., Ramkumar, K. Niranjankumar and S. K. Mehta, J. Geophys. Res., 115, D24109,doi:10.1029/2009JD013733, 2010 (*Citations*: 5).
239. Differences in Cyclonic Raindrop Size Distribution from Southwest to Northeast MonsoonSeason and from that of in Non-cyclonic Rain, Radhakrishna, B. and T. N. Rao, J. Geophys.Res., 115, D16205, doi:10.1029/2009JD013355, 2010 (*Citations*: 8).
240. Turbulence associated with mountain waves over Northern Scandinavia – a case study usingESRAD VHF radar and the WRF mesoscale model, S. Kirkwood, M. Mihalikova, T. N. Rao and K. Satheesan, Atmos. Chem. Phys., 10, 3583-3599, 2010 (*Citations*: 19).
241. Observation of precipitation and dropsize distribution associated with a typhoon using VHF radar, Anandan, V. K., C. J. Pan, K. K. Reddy and T. N. Rao and S.V.B. Rao, The Open Atmos. Sci. J., 4, 114-125, 2010 (*Citations: Nil*).
242. Compact Dual Polarization Lidar system description and data processing, Y. Bhavani Kumar, Int. J. Computer Sci. Engg., 2, 2684-2689, 2010 (*Citations: Nil*).
243. Development of lidar techniques for environmental remote sensing, Y. Bhavani Kumar, M. Sundara Murthy and M. Krishnaiah, Int. J. Engg. Sci. Tech., 2, 5872-5881, 2010 (*Citations: Nil*).
244. An algorithm for retrieval of aerosol properties from lidar observations, Y. Bhavani Kumar and S. Vijaya Kumar Varma, Int. J. Engg. Sci. Tech., 2, 4043-4050, 2010 (*Citations: Nil*).

245. Mathematical algorithms for determination of mixed layer height from laser radar signals, Y. Bhavani Kumar and S. Purusotham, Int. J. Computer Sci. Engg., 2(6), 2059-2063, 2010 (*Citations*: 2).
246. Mesospheric sodium over Gadanki during Geminid meteor shower 2007, B. Lokanadham, N. Rakesh Chandra, S. Vijaya Bhaskara Rao, K. Raghunath, G. Yellaiah, Ind J. Radio & Space Phys, 39, 7-10, 2010 (*Citations*: 3).

2011

247. Current knowledge on low-latitude mesospheric thermal structure, M. V. Ratnam, P. Kishore, A. K. Patra and B. V. Krishna Murhty, Asian J. Phy., 19, 1-12, 2011 (*Citations: Nil*)
248. Short period mesospheric wave measurements by optical means over Gadanki (13.8^{o} N, 79.2^{o} E) during May 2009, A. Taori, V. Kamalakar and S. V. B. Rao, Asian J. Phys., 19, 321-328, 2011 (*Citations: Nil*).
249. Near simultaneous lidar observations of upper mesospheric temperature inversion layers and sporadic Na layers over Gadanki (13.5°N, 79.2°E), S. Sridharan, K. Ramesh, S. Sathishkumar, S. Gurubaran, K Raghunath, Y. Bhavani Kumar, S. Vijaya Bhaskara Rao, Asian J. Phys, 19, 2010, 13-1183, 2010 (*Citations: Nil*).
250. VHF radar observed characteristic of convectively generated gravity waves during wet anddry spells of Indian summer monsoon, K. N. Uma, K. K. Kumar and T. N. Rao, J. Atmos.Sol.Terr. Phys., 73, 815-824, 2011 (*Citations*: 9).
251. Unusual enhancement in temperature and Ozone vertical distribution in the lower Stratosphere observed over Gadanki, India, following 15 January 2010 annular eclipse, M. VenkatRatnam, GhouseBasha, M. Roja Raman, Sanjay Kumar Mehta, B.V. KrishnaMurthy and A. Jayaraman, Geophys. Res. Lett., 38, L02803, doi:10.1029/2010GL045903, 2011 (*Citations*: 11).
252. Sub-daily variations observed in Tropical Easterly Jet (TEJ) streams, M. VenkatRatnam, M.Roja Raman, Sanjay Kumar Mehta, DebashisNath, B. V. Krishnamurthy, M. Rajeevan, S.VijayaBhaskara Rao and D. Narayana Rao, J. Atmos. Sol.Terr. Phys., 73, 731–7402011, 2011 (*Citations*: 4).
253. Reply to the comments of Le et al. (2011) on the paper "Total solar eclipse of July 22, 2009: Its impact on the total electron content and ionospheric electron density in the Indian Zone" by Sharma et al.(2010), Shweta Sharma, P. Galav, N. Dashora and R. Pandey, J. Atmos. Sol.Terr. Phys., doi:10.1016/j.jastp.2011.03.011, 2011 (*Citations: Nil*).
254. Evaluation of the ENSEMBLES multi-model seasonal forecasts of Indian summer monsoonvariability, M. Rajeevan, C.K.Unnikrishnan and B.Preethi, Cli. Dyn., Dynamics, DOI10.1007/s00382-011-1061-1, 2011 (*Citations*: 40).
255. Role of intra-seasonal oscillations in modulating Indian summer monsoon rainfall, A. Kulkarni, R. Kripalani, S.Sabade and M. Rajeevan, Cli. Dyn., DOI 10.1007/s00382-010-0973-1, 2011 (*Citations*: 9).
256. Cycle slip detection, correction and phase leveling of RINEX formatted GPS Observables, S. Sharma, N. Dashora, P. Galav and R. Pandey, Curr. Sci., 100, 205-212, 2011 (*Citations*: 13).

257. Doppler SODAR observations of the temperature structure parameter during monsoon seasonover a tropical rural station, Gadanki, M. Shravan Kumar, V. K. Anandan, A. Kesarkar andP. Narasimha Reddy, J. Earth Sys. Sci., 120, 65-72, 2011 (*Citations*: 2).
258. Gravity wave seeding of equatorial plasma bubbles: an investigation with simultaneous Fregion,E-region and middle atmospheric measurements, A. Taori, A. K. Patra and L. M.Joshi, J. Geophys. Res., doi:10.1029/2010JA016229, 2011 (*Citations*: 13).
259. A case of sudden variation in nocturnal mesospheric temperatures: Variability and its causative mechanism, A. Taori, A. P. Kesarkar, K. Niranjan Kumar and T. K. Ramkumar, J. Atmos. Sol. Terr. Phys., doi:10.1016/j.jastp.2011.04.020, 2011 (*Citations*: 4).
260. A study of vertical cloud structure of the Indian summer monsoon using Cloud Sat data, M. Rajeevan, P. Rohini, K. Niranjan Kumar, J. Srinivasan and C. K. Unnikrishnan, Clim. Dyn., DOI 10.1007/s00382-012-1374-4, 2012 (*Citations*: 18).
261. Atmospheric temperature variability with modified lidar error analysis, D. Praveen Kumar, K. Raghunath and B. Anuradha, J. Optics., 40, 77–83, 2011 (*Citations: Nil*).
262. Characteristics of 150 km echoes linked with solar eclipse and their implications to the echoing phenomenon, A. K. Patra, P. P. Chaitanya and D. Tiwari, J. Geophys. Res., 116, A05319, doi:10.1029/2010JA016258, 2011 (*Citations*: 4).
263. Characteristics of the Tropical Tropopause over Different Longitudes, Sanjay Kumar Mehta, M. Venkat Ratnam and B.V. Krishna Murthy, J. Atmos. Sol. Terr. Phys., 73, 2462–2473, doi:10.1016/l.jastp.2011.08.005, 2011 (*Citations*: 4).
264. Descending ion layer property in the Gadanki radar observations of 150 km echoes and its implication to the echoing phenomenon, A. K. Patra, J. Geophys. Res., 116, A11322, doi:10.1029/2011JA016805, 2011 (*Citations*: 4).
265. Global distribution of water vapor observed by COSMIC GPS RO: Comparison with GPS radiosonde, NCEP, ERA-Interim and JRA-25 reanalysis data sets, P. Kishore, M. Venkat Ratnam, S. P. Namboothiri, Isabella Velicogna, Ghouse Basha, J. H. Jiang, K. Igarashi, S. Vijaya Bhaskara Rao and V. Sivakumar, J. Atmos. Sol. Terr. Phys., 73, 1849–1860, doi:10.1016/j.jastp.2011.04.017, 2011 (*Citations: Nil*).
266. In-cloud and below-cloud scavenging of aerosol ionic species over a tropical rural atmosphere in India, A. Chatterjee, A. Jayaraman, T. N. Rao and S. Raha, J. Atmos. Chem., DOI 10.1007/s10874-011-9190-5, 2011 (*Citations*: 3).
267. Intriguing aspects of monsoon low level jet over peninsular India revealed by high-resolution GPS radiosonde observations, M. Roja Raman, M. Venkat Ratnam, M. Rajeevan,V. V. M. Jagannadha Rao and S. Vijaya Bhaskara Rao, J. Atmos. Sci., 68, 1413-1423,DOI: 10.1175/2011JAS3611.1, 2011 (*Citations*: 7).
268. Investigation of low-latitude E and valley region irregularities: Their relationship to equatorial plasma bubble bifurcation, G. Li, B. Ning, A. K. Patra, W. Wan and L. Hu, J. Geophys. Res., 116, A11319, doi: 10.1029/2011JA016895, 2011 (*Citations*: 16).
269. Investigations on the physical and optical properties of cirrus clouds and their relationship with ice nuclei concentration using LIDAR at Gadanki, India (13.5ºN, 79.2ºE), V. Krishnakumar, M. Satyanarayana, S. R. Radhakrishnan, Reji K. Dhaman,V. P. Mahadevan Pillai, K. Raghunath, M. Venkat Ratnam, D. Ramakrishna Rao and P. Sudhakar, J. Appl. Rem. Sen., 5, 2011 (*Citations: Nil*).
270. Longitudinal study of the ionospheric response to the geomagnetic storm of 15 May 2005 and manifestation of TADs, S. Sharma, P. Galav, N. Dashora and R. Pandey, Ann. Geophys., 29, 1063–1070, 2011 (*Citations*: 11).

271. Long-term variations in outgoing long-wave radiation (OLR), convective available potential energy (CAPE) and temperature in the tropopause region over India, R. Sapra, S. K. Dhaka, V. Panwar, R. Bhatnagar, K. Praveen Kumar, Shibagaki, M. Venkat Ratnam and M. Takahashi, J. Earth Sys. Sci., 120, 5, 1–17, 2011 (*Citations*: 5).
272. Low-latitude Mesospheric Vertical Winds Observed Using VHF Radar, S. Eswaraiah, M. Venkat Ratnam, B.V. Krishna Murthy and S. Vijaya Bhaskara Rao, J. Geophys. Res., 116, D22117, doi:10.1029/2011JD016385, 2011 (*Citations*: 2).
273. Middle atmospheric thermal structure over sub-tropical and tropical Indian Locations using lidar, Som Sharma, S. Sridharan, H Chandra, S. Lal and Y. B. Acharya, Plan. Space Sci., doi:10.1016/j.pss.201110.015, 2011 (*Citations*: 1).
274. MST Radar observation of inertia-gravity waves generated from tropical cyclones, K. Niranjan Kumar, T.K. Ramkumar and M. Krishnaiah, J. Atmos. Sol. Terr. Phys., doi:10.1016/j.jastp.2011.04.026, 2011 (*Citations*: 4).
275. Multiple Tropopauses in the Tropics: A Cold Point Approach, Sanjay Kumar Mehta, M. Venkat Ratnam and B.V. Krishna Murthy, J. Geophys. Res., 116, D20105, doi:10.1029/2011JD016637, 2011 (*Citations*: 6).
276. Northeast monsoon variability over south peninsular India and its teleconnections, P. P. Sreekala, S. Vijaya Bhaskara Rao and M. Rajeevan, Theor. Appl. Climatol., DOI 10.1007/s00704-011-0513, 2011 (*Citations*: 7).
277. Observational evidence of deep convection over Indonesian sector in relation with major stratospheric warming events of 2003–04 and 2005–06, S. Sridharan and S. Sathishkumar, J. Atmos. Sol. Terr. Phys., doi:10.1016/j.jastp.2011.09.007, 2011 (*Citations*: 1).
278. Observations of 2-4 day inertia-gravity wave from equatorial troposphere to F-region during the sudden stratospheric warming event of 2009, S. Sathishkumar and S. Sridharan, J. Geophys. Res., doi:10.1029/2011JA017096, 2011 (*Citations*: 4).
279. On the role of dust storms in triggering atmospheric gravity waves observed in the middle atmosphere, S. K. Das, A. Taori and A. Jayaraman, Ann. Geophys. 29, 1647-1654, doi:10.5194/angeo-29-1647-2011, 2011 (*Citations*: 8).
280. Prediction and classification of thunderstorms using Artificial Neural Network, S. Mahesh Anand, Ansupa Dash, M. S. Jagadeesh Kumar and Amit Kesarkar, Int. J. Eng. Sci. Tech., 3, 4031 – 4035, 2011 (*Citations*: 5).
281. Radiative effects of elevated aerosol layer in Central Himalayas, P. Kishore, P. Pant, D. V. Phani Kumar, U. C. Dumka, Y. Bhavani Kumar, N. Singh and H. Joshi, Int. J. Rem. Sens., 32, 9721-9734, 2011 (*Citations*: 3).
282. Response of low latitude ionospheric total electron content to the geomagnetic storm of 24 August 2005, S. Sharma, P. Galav, N. Dashora, S. Alex, R. S. Dabas and R. Pandey, J. Geophys. Res., 116, A05317, doi:10.1029/2010JA016368, 2011 (*Citations*: 6).
283. Response of tropical lower atmosphere to annual solar eclipse of 15 January 2010, Gopa Dutta, P. Vinay Kumar, M. Venkat Ratnam, Salauddin Mohammad, M. C. Ajay Kumar, P. V. Rao, K. Rahaman and H. A. Basha, J. Atmos. Sol. Terr. Phys., 73, 1907-1914, doi:10.1016/j.jastp.2011.04.025, 2011 (*Citations*: 3).
284. Simplified Active Array L-Band Radar for Atmospheric Wind Profiling: Initial Results, P. Srinivasulu, P. Yasodha, S. N. Reddy, S. Satyanarayna and A. Jayaraman, J. Atmos. Ocean.Tech., 28, 1436-1447, 2011 (*Citations*: 14).

285. Simultaneous bi-station measurements of mesospheric waves from Indian low latitudes, A. Taori and N. Parihar, Adv. Space Res., 48, 218 – 226, doi:10.1016/j.asr.2011.03.026, 2011 (*Citations*: 4).
286. Simultaneous mesosphere thermosphere-ionosphere parameter measurements over Gadanki (13.5°N, 79.2°E): First results, A. Taori, N. Dashora, K. Raghunath, J. M. Russell III and M. G. Mlynczak, J. Geophys. Res., 116, A07308, doi:10.1029/ 2010JA016154, 2011 (*Citations*: 16).
287. Simultaneous Rayleigh lidar and airglow measurements of middle atmospheric waves over low latitudes in India, A. Taori, V. Kamalakar, K. Raghunath, S. V. B. Rao and J. M. Russell III, J. Atmos. Sol. Terr. Phys., doi:10.1016/j.jastp.2011.06.012, 2011 (*Citations*: 9).
288. South Asian Regional Summary, M. Rajeevan, A. K. Srivastava, Z. Lareef and J. Revadekar, State of the Climate in 2010, Bull. Amer. Meteor. Soc., 92, S217-S219, 2011 (*Citations: Nil*).
289. Study of ionospheric TEC during space weather event of 24 August 2005 at two different longitudes, Sharma, S., P. Galav, N. Dashora, R. S. Dabas and R. Pandey, J. Atmos. Sol. Terr. Phys., doi:10.1016/j.jastp.2011.05.006, 2011 (*Citations*: 10).
290. Variabilities of mesospheric tides during sudden stratospheric warming events of 2006 and 2009 and their relationship with ozone and water vapour, S. Sridharan, S. Sathishkumar and S. Gurubaran, J. Atmos. Sol. Terr. Phys., doi:10.1016/ j.jastp.2011.03.013, 2011 (*Citations*: 20).
291. Vertical and lateral propagation characteristics of Intra Seasonal Oscillation (ISO) from the tropical lower troposphere to upper mesosphere, K. Niranjan kumar, T. K. Ramkumar and M. Krishnaiah, J. Geophys. Res., doi:10.1029/ 2010JD015283, 2011 (*Citations*: 6).
292. Influence of south Asian dust storm on aerosol radiative forcing at high-altitude station in central Himalayas, A. K. Srivastava, P. Pant, P. Hegde, S. Singh, U.C. Dumka, M. Naja, N. Singh and Y. Bhavani Kumar, Int. J. Rem. Sens., 32(22), 7827-7845, 2011 (*Citations*: 23).
293. Development of lidar technologies under project LIDAR, Y. Bhavani Kumar, Int. J. Adv. Engg. Sci. Tech., 10, 160-165, 2011 (*Citations: Nil*).
294. Tropical stratopause features - Rayleigh lidar observations over Gadanki (13.5°N,79.2°E), India, U. Jaya Prakash Raju, M. Krishnaiah, Y. Bhavani Kumar, D. Kothandan and P. Keckhut, Adv. Appl. Sci. Res., 2, 318-331, 2011 (*Citations*: 9).
295. Atmospheric temperature variability with modified lidar error analysis, D Praveen Kumar, K Raghunath and B Anuradha, J. Optics, 40, 77–83, 2011 (*Citations: Nil*).

2012

296. A new method to derive middle atmospheric temperature profiles using a combination of Rayleigh lidar and O_2 airglow temperatures measurements, A. Taori, A. Jayaraman, K. Raghunath and V. Kamalakar, Ann. Geophys., 30, 27-32, doi:10.5194/angeo-30-27-2012, 2012 (*Citations*: 5).
297. Detection of high frequency gravity waves using high resolution radiosonde observations, P. P. Leena, M. Venkat Ratnam, B.V. Krishna Murthy and S. Vijaya

Bhaskara Rao, J. Atmos. Sol. Terr. Phys., 77, 254-259, doi:10.1016/ l.jastp.2012.01.003, 2012 (*Citations*: 4).

298. An Overview of CAWSES-India Program with Emphasis to Equatorial Atmospheric Coupling Processes, P. B. Rao, Beig, G, R. S. Dabas, Geetha Ramkumar, S. Gurubaran, Kusuma G Rao, P. K. Manoharan, A. K. Patra, Sudha Ravindran, Tarun K Pant, M. Venkat Ratnam, S. C. Chakravart and R. Sridharan, J. Atmos. Sol. Terr. Phys., 75-76, 98-114, doi:10.1016/l.jastp.2011.08.005, 2012 (*Citations*: 4).
299. Characteristics of the intra-seasonal oscillations in the lower and middle atmosphere over Gadanki, A. Guharay, R. Sekar, M. Venkat Ratnam and P. P. Batista, J. Atmos. Sol. Terr. Phys.,77, 167-173, doi:10.1016/l.jastp.2011.12.016, 2012 (*Citations*: 4).
300. Climatological study of the Nocturnal Boundary Layer over a complex terrain station, M. Shravan kumar, V. K. Anandan, T. N. Rao and P. N. Reddy, J. Appl. Meteorol. Climatol., 51, 813-825, 2012 (*Citations*: 5).
301. Development of a perfect prognosis probabilistic model for prediction of lightning over southeast India, M. Rajeevan, A. Madhulatha, M. Rajasekhar, Jyoti Bhate, Amit Kesarkar and B. V. Appa Rao, J. Earth. Sys. Sci., 121, 355-371, 2012 (*Citations*: 6).
302. First measurement of upper mesospheric semi annual oscillations using ground based airglow measurements from Indian low latitudes, A. Taori, V. Kamalakar and A. Jayaraman, Adv. Space Res., 49, 937-942, doi:10.1016/j.asr.2011.12.016, 2012 (*Citations*: 3).
303. On the importance of wave-like structures in the occurrence of equatorial plasma bubbles: A case study, V.L. Narayanan, A. Taori, A. K. Patra, K. Emperumal and S. Gurubaran, J. Geophys. Res., 117, A01306, doi:10.1029/2011JA017054, 2012 (*Citations*: 14).
304. On the vertical distribution of mean vertical velocities in the convective regions during the wet and dry spells of monsoon over Gadanki, K. N. Uma, K. K. Kumar, S. S. Das, T. N. Rao and T. M. Satyanarayana, Mon. Wea. Rev., 140, 398-410, 2012 (*Citations*: 3).
305. Northeast monsoon over India: variability and prediction, M. Rajeevan, C. K. Unnikrishnan, Jyoti Bhate, K. Niranjan Kumar and P. P. Sreekala, Meteorol. Appl., DOI: 10.1002/met.1322, 2012 (*Citations*: 5).
306. Role of Tropical Convective Cells in the Observed Middle Atmospheric Gravity Wave Properties from Two Distant Low Latitude Stations, A. Taori, S. Raizada, M. Venkat Ratnam, C. A. Tepley, D. Nath and A. Jayaraman, Earth Sci. Res., 1, 87-97, doi:10.5539/esr.v1n1p87, 2012 (*Citations*: 4).
307. Study on deep inland penetration of sea breeze over complex terrain in the tropics, M. Shravan Kumar, V. K. Anandan, Amit Kesarkar, S.Vijaya Bhaskara Rao and P. Narasimha Reddy, Atmos. Res., 104 – 105, 209 – 216, 2012 (*Citations*: 4).
308. 1280 MHz active array radar wind profiler for lower atmosphere: System description and data mvalidation, P. Srinivasulu, P. Yasodha, S. N. Reddy, P. Kamaraj, T. N. Rao, S. Satyanarayana and A. Jayaraman, J. Atmos. Ocean. Tech., 29, 1455-1470, 2012 (*Citations*: 15).
309. A Comparative study of equatorial daytime vertical ExB drift in the Indian and Indonesian sectors based on 150 km echoes, A. K. Patra, P. Pavan Chaitanya, N. Mizutani, Y. Otsuka, T. Yokoyama and M. Yamamoto, J. Geophys. Res., 117, A11312, doi:10.1029/2012JA018053, 2012 (*Citations*: 12).

310. Altitudinal and latitudinal asymmetry in diurnal variation of sporadic meteor flux observed over Thumba, D. V. Phanikumar, Y.-S. Kwak, A. K. Patra, K. Kishore Kumar and G. Yellaiah, Curr. Sci., 103, 62-67, 2012 (*Citations*: 1).
311. An unusual reduction in the mesospheric semi-diurnal tidal amplitude over Tirunelveli (8.7°N, 77.8°E) prior to the 2011 minor warming and its relationship with stratospheric ozone, S. Sridharan, S. Sathishkumar and S. Gurubaran, J. Atmos. Sol. Terr. Phys., 89, 27-32, 2012 (*Citations*: 1).
312. Analysis of large-amplitude stratospheric mountain wave event observed from the AIRS and MLS sounders over the western Himalayan region, K. Niranjan Kumar, T. K. Ramkumar and M. Krishnaiah, J. Geophys. Res., 117 D22, DOI: 10.1029/2011JD017410, 2012 (*Citations*: 3).
313. Comparison of mesospheric mean vertical winds between MST radar and empirical model over a tropical station, S. Eswaraiah, M. V. Ratnam, Y. I. Portnyagin, E. Merzlyakov and S. V. B. Rao, Curr. Sci., 102, 9, 1298-1303, 2012 (*Citations: Nil*).
314. Contrasting features of the F3 layer during high and low solar activity conditions observed from Indian low latitude, P. Pavan Chaitanya, A. K. Patra and S. V. B. Rao, Ind. J.Radio Space Phys., 41, 121-129, 2012 (*Citations*: 4).
315. Effect of the annular solar eclipse of 15 January 2010 on the low latitude mesosphere, M. V. Ratnam, S. Eswaraiah, P. P. Leena, A. K. Patra, B.V. Krishna Murthy and S. V. B. Rao, J. Atmos. Sol. Terr. Phys., 80, 340–346, 2012 (*Citations*: 4).
316. Equatorial F-region irregularities during low and high solar activity conditions, L. M. Joshi, A. K. Patra and S. V. B. Rao, Ind. J.Radio Space Phys., 41, 208-219, 2012 (*Citations*: 4).
317. Equinoctial and June solstitial F-region irregularities over Sanya, G. Li, B. Ning, L. Liu, W. Wan, L. Hu, B. Zhao and A. K. Patra, Ind. J. Radio & Space Phys., 41, 184-198, 2012 (*Citations*: 9).
318. Fabry Perot interferometer as solar background noise suppressor: Application to daytime lidar, K. Raghunath, K. Ramesh and S. N. Reddy, Ann. Geophys., 55, 2, doi: 10.4401/ag-4947, 2012 (*Citations: Nil*).
319. Inertia gravity wave characteristics and associated fluxes observed using five years of radiosonde measurements over a tropical station, P. P. Leena, M. V. Ratnam and B.V. Krishna Murthy, J. Atmos. Solar Terr. Phys. 84–85, 37–44, 2012 (*Citations*: 7).
320. Large mesospheric inversion layer due to breaking of small-scale gravity waves: Evidence from Rayleigh lidar observations over Gadanki (13.5°N, 79.2°E), K. Ramesh and S. Sridharan, J. Atmos. Sol. Terr. Phys., 89, 90-97, 2012 (*Citations*: 3).
321. Laser Radar system for the characterization of boundary layer using modified wavelet covariance transform, P. Ravi Kumar, G. Suresh, Y. Bhavani Kumar and D. Arun Kumar, Int. J. Elect. Comm. Eng. Tech., 3(2), 474-483, 2012 (*Citations: Nil*).
322. Low latitude mesospheric turbulence investigated using coordinated MST radar and rocket-borne observations from India, H. Chandra, H. S. S. Sinha, A. K. Patra, U. Das, D. Selvaraj, R. N. Misra and J. Datta, J. Geophys. Res., 117, D22109, doi:10.1029/2011JD016946, 2012 (*Citations*: 2).
323. Multi-instrument observations of winter solstice F-region irregularities during low solar activity, N. Dashora, A. Taori and A. K. Patra, Ind. J.Radio & SpacePhys.,41, 220-232, 2012 (*Citations*: 4).
324. On the linkage between mesospheric gravity waves and occurrence of equatorial plasma bubble observed during the low solar activity, A. Taori, V. Kamalakar, L. M.

Joshi, S. Sripathi and A. K. Patra, Ind. J. Radio & Space Phys.,41, 264-270, 2012 (*Citations*: 4).

325. On the linkage of mesospheric planetary waves with those of the lower atmosphere and ionosphere - A case study from Indian low latitudes, K. Niranjan Kumar, A. Taori, S. Sathishkumar, V. Kamalakar, R. Ghodpage, S. Gurubaran, P. T. Patil, S. V. B. Rao and A. K. Patra, J. Geophys. Res., 117, A11303, doi:10.1029/2012JA018139, 2012 (*Citations*: 3).
326. On the nature of radar backscatter and 250 MHz scintillation linked with an intense daytime Es patch, A. K. Patra, P. P. Chaitanya and A. Bhattacharyya, J. Geophys. Res., 117, A03315, doi:10.1029/2011JA016981, 2012 (*Citations*: 6).
327. Performance simulations of Rayleigh Doppler lidar system for measuring middle atmosphere winds, K. Raghunath and S. N. Reddy, Sci. Res. & Essays, 7, 2440-2447, 2012 (*Citations: Nil*).
328. Planetary waves in the upper stratosphere and lower mesosphere during 2009 Arctic major stratospheric warming, P. Kishore, I. Velicogna, M. V. Ratnam, J. H. Jiang and G. N. Madhavi, Ann. Geophys., 30, 1529-1538, 2012 (*Citations*: 2).
329. Regional climate model simulations of the 2009 Indian summer monsoon, J. Bhate, C. K. Unnikrishnan and M. Rajeevan, Ind. J.Radio Space Phys., 41, 488-500, 2012 (*Citations*: 2).
330. Relationship between stable isotope ratios and drop size distribution in tropical rainfall, R. Srivastava, R. Ramesh and T. N. Rao, J. Atmos. Chem., DOI 10.1007/s10874-012-9227-4, 2012 (*Citations*: 3).
331. Sensitivity of Z-R relations and spatial variability of error in a Doppler weather radar measured rain intensity, D.Dutta, S. Sharma, B. A. M. Kannan, S. Venkateswarlu, R. N. Gairola, T. N. Rao and G Viswanathan, Ind. J.Radio Space Phys., 41, 448-460, 2012 (*Citations: Nil*).
332. Spectral characteristics and scatter cross-section of low latitude mesospheric echoes measured by the Indian MST radar at Gadanki, E. Belova, S. Kirkwood, T. N. Rao, S. Satheesh kumar and T. Sergienko, Ann. Geophys., 30, 983-990, 2012 (*Citations*: 1).
333. Time series regression models for the temperature of global, land and ocean, S. Venkatramana Reddy, G. K. K. Reddy, M. Naresh, S.C. Thasleema, B. Sarojamma, R. Rajanikanth and T. K. Ramkumar, Int. J. Environ. Res. Develop. 2, 109-121, 2012 (*Citations: Nil*).
334. Variability of raindrop size distribution and its impact on polarimetric rain rate estimators, K. Amarjyothi and T. N. Rao, Ind. J.Radio & Space Phys., 41, 471-480, 2012 (*Citations*: 1).
335. Variability of the thermal structure of the atmosphere during wet and dry spells over southeast India, T. S. Mohan and T. N. Rao, Q. J. Royal Meteorol. Soc., 138, 1839-1851, 2012 (*Citations*: 2).
336. Preliminary observation of temperature profiles by radio acoustic sounding system (RASS) with a 1280 MHz lower atmospheric wind profiler at Gadanki, India, T.V.Chandrasekhar Sarma, P. Srinivasulu, T. Tsuda, Atmos. Meas. Tech. Discuss., 5, 4447-4472, 2012 (*Citations: Nil*).

2013

337. A case study of mesospheric wave periods and horizontal structures over a low latitude station, Allahabad (India), N. Parihar, A. Taori, V. Kamalakar and S. V. B. Rao, Adv. Space. Res., 21, doi:10.5539/esr.v2n1p1, 2013 (*Citations*: 1).
338. Anomalous propagation conditions observed over a tropical station using high resolution GPS radiosonde observations, G. Basha, M. V. Ratnam, G. Manjula and A.V. Chandra Sekhar, Radio Sci., 48, 42-49, doi:10.1002/rds.20012, 2013 (*Citations: Nil*).
339. Characteristics of the multiple tropopauses in the tropics, S. K. Mehta, M. V. Ratnam and B.V. KrishnaMurthy, J. Atmos. Sol. Terr. Phys., 95–96, 78–86, 2013 (*Citations*: 2).
340. Direct detection of wavelike spatial structure at the bottom of the F region and its role on the formation of equatorial plasma bubble, A. K. Patra, A. Taori, P. P. Chaitanya and S. Sripathi, J. Geophys. Res., 118, 1–7, doi:10.1002/jgra.50148, 2013 (*Citations*: 7).
341. Diurnal variability of stability indices observed using radiosonde observations over a tropical station: Comparison with microwave radiometer measurements, M. V. Ratnam, Y. Durga Santhi, M. Rajeevan and S. V. B. Rao, Atmos. Res., 124, 21–33, 2013 (*Citations*: 20).
342. Evidence of long-term change in zonal wind in the tropical lower mesosphere: Observations and model simulations, M. V. Ratnam, G. Kishore Kumar, N. Venkateswara Rao, B. V. KrishnaMurthy, J. Lastovicka and L. Qian, Geophys. Res. Lett., 40, 1-5, doi:10.1002/grl.50158, 2013 (*Citations*: 8).
343. Global distribution of pauses observed with satellite measurements, M. V. Ratnam, P. Kishore and I. Velicogna, J. Earth Syst. Sci., 122, 515-529, 2013 (*Citations: Nil*).
344. Identification of coherent rainfall zones over India, K. Saikranthi, T. N. Rao, M. Rajeevan and S. V. B. Rao, J. Hydrometeorol, 14, 304-317, 2013 (*Citations*: 2).
345. Imaging of mesosphere-thermosphere airglow emissions over Gadanki (13.5°N, 79.2°E) – first results, A. Taori, A. Jayaraman and V. Kamalakar, J. Atmos. Sol. Terr. Phys., 93, 21-28, doi:10.1016/j.jastp.2012.11.007, 2013 (*Citations*: 10).
346. Investigation of Radiative Effects of Optically Thick Dust Layer over Indian Tropical Region, S. K. Das, J.-P. Chen, M. V. Ratnam and A. Jayaraman, Ann. Geophys., 31, 647–663, 2013 (*Citations*: 5).
347. Lower stratospheric gravity wave activity over Gadanki (13.5°N, 79.2°E) during the stratospheric sudden warming of 2009: Link with potential vorticity intrusion near Indian sector, D. Nath, S. Sridharan, S. Sathishkumar, S.Gurubaran and W. Chen, J. Atmos. Sol. Terr. Phys., 94, 54-64, 2013 (*Citations*: 5).
348. Low-latitude Es capable of controlling the onset of equatorial spread F, L. M. Joshi, A. K. Patra and S. V. B. Rao, J. Geophys. Res., 118, 1170–1179, doi:10.1002/jgra.50189, 2013 (*Citations: Nil*).
349. Lunar and solar tidal variabilities in mesospheric winds and EEJ strength over Tirunelveli (8.7°N, 77.8°E) during the 2009 major stratospheric warming, S. Sathishkumar and S. Sridharan, J. Geophys. Res., 118, 533-541, 2013 (*Citations*: 6).
350. Morphology of tropical mesospheric echoes observed by VHF radar, M. V. Ratnam, G. Kishore Kumar, S. Eswaraiah and S. V. B. Rao, Earth Planets Space, 65, 97–102, 2013 (*Citations: Nil*).
351. Nowcasting severe convective activity over South-east India using ground-based microwave radiometer observations, A. Madhulatha, M. Rajeevan, M. V. Ratnam, J. Bhate and C.V. Naidu, J. Geophys. Res., doi: 10.1029/2012JD018174, 2013 (*Citations*: 17).

352. On the detection of onset and activity of Indian summer monsoon using GPS RO refractivity profiles, V. V. M. JagannadhaRao, M. V. Ratnam, Y. Durga Santhi, M. Roja Raman, M. Rajeevan and S. V. B. Rao, Mon. Wea. Rev., 2096-2106, 2013 (*Citations*: 1).
353. On the nature of low-latitude Es influencing the genesis of equatorial plasma bubble, L. M. Joshi, A. K. Patra, T. K. Pant and S. V. B. Rao, J. Geophys. Res., 118, 524–532, doi:10.1029/2012JA018122, 2013 (*Citations*: 3).
354. Seasonal variation of surface and vertical profile of aerosol properties over a tropical urban station Hyderabad, India, P. R. Sinha, R. K. Manchanda, D. G. Kaskaoutis, Y. B. Kumar and S. Sreenivasan, J. Geophys. Res., 118, 1–20, doi:10.1029/2012 JD018039, 2013 (*Citations*: 7).
355. Simultaneous measurement of OI 557.7 nm, O2 (0, 1) Atmospheric Band and OH (6, 2) Meinel Band nightglow at Kolhapur (17oN), India, N. Parihar, A. Taori, S. Gurubaran and G. K. Mukherjee, Ann. Geophys., 1, 197–208,doi:10.5194/angeo-31-197-2013, 2013 (*Citations*: 2).
356. Simultaneous mesospheric gravity wave measurements in OH night airglow emission from Gadanki and Kolhapur – Indian low latitudes, R. N. Ghodpage, A. Taori, P. T. Patil and S. Gurubaran, Curr. Sci., 104, 1, 98 – 104, 2013 (*Citations*: 3).
357. Temporal and spatial variability of aerosol optical depth over South India as inferred from MODIS, T. Kiran Kumar, H. Gadhavi, A. Jayaraman, M. N. SaiSuman and S. V. B. Rao, J. Atmos. Sol. Terr. Phys., 94, 71-80. doi: 10.1016/j.jastp.2012.12.010, 2013 (*Citations*: 2).
358. First simultaneous observations of F3 layer and ExB drift in Indian sector and modeling, P. PavanChaitanya, A. K. Patra, N. Balan and S. V. B. Rao, J. Geophys. Res., 118, 3527–3539, doi:10.1002/jgra.50298, 2013 (*Citations*: 2).
359. Impact of misrepresentation of freezing level height by TRMM on shallow rain statistics over India and adjoining oceans, K. Saikranthi, T. N. Rao, B. Radhakrishna, S.V.B. Rao, J. App. Meteorol. Climatol., 52, 2001-2008, 2013 (*Citations*: 2).
360. Is the trend in TEJ reversing over the Indian subcontinent? M. VenkatRatnam, B.V. Krishna Murthy and A. Jayaraman, Geophy. Res. Lett. 40, 3446–3449, doi:10.1002/grl.50519, 2013 (*Citations*: 2).
361. Large scale features and assessment of spatial scale correspondence between TMPA and IMD rainfall datasets over Indian landmass, R. Uma, T. V. Lakshmi Kumar, M. S. Narayanan, M. Rajeevan, JyotiBhate and K Niranjan Kumar, J. Earth Sys. Sci., 122, 3, 573–588, 2013 (*Citations*: 7).
362. Airborne particles washout: A case study investigated using laser radar, B. Gayathri and Y. Bhavani Kumar, Int. J. Eng. and Tech., 5, 4241 – 4246, 2013 (*Citations: Nil*).
363. LIDAR for atmospheric measurement and probing, T. Cherian, Y. Bhavani Kumar and B. Sudharshan Reddy, Int. J. Eng. and Tech., 5, 5114 – 5124, 2013 (*Citations: Nil*).
364. Micro pulse lidar as a tool for active remote sensing of atmospheric particulate, M. Sudharshan Reddy and Y. Bhavani Kumar, Int. J. Eng. and Tech., 5 (4), 3394 – 3403, 2013 (*Citations*: 3).
365. Moisture Variability over Indian monsoon regions observed using high resolution radiosonde measurements, Ghouse Basha and M. VenkatRatnam, Atmos. Res., 132–133, 35–45, 2013 (*Citations*: 2).
366. On the linkage of daytime 150 km echoes and abnormal intermediate layer traces over Sanya, G. Li, B. Ning, A.K. Patra, M. A. Abdu, J. Chen, L. Liu and L. Hu, J. Geophys. Res., 118, 7262–7267, doi:10.1002/2013JA019462, 2013 (*Citations*: 7).

367. On the Rayleigh Lidar capability enhancement for the measurements of waves at upper mesospheric altitudes having periodicity 0.5 to 2.0 hr, V. Kamalakar, A. Taori, K. Raghunath, S. V. B. Rao and A. Jayaraman, Int. J. Rem. Sen., 34, 21, 7474-7486, doi: 10.1080/01431161.2013.822599, 2013 (*Citations*: 1).
368. Planetary wave-gravity wave interactions during mesospheric inversion layer events, K. Ramesh, S. Sridharan, K. Raghunath, S. Vijaya Bhaskara Rao and Y. Bhavani Kumar, J. Geophys. Res., 118, 4503 – 4515, 2013 (*Citations*: 3).
369. Relative humidity distribution from SAPHIR experiment on board Megha-Tropiques satellite mission: Comparison with global radiosonde and other satellite and reanalysis data sets, M. VenkatRatnam, G. Basha, B. V. Krishna Murthy and A. Jayaraman, J. Geophys. Res., 118, 9622–9630, doi:10.1002/jgrd.50699, 2013 (*Citations*: 2).
370. Short Period Gravity Wave Momentum Fluxes Observed in the Tropical Troposphere, Stratosphere and Mesosphere, S. Eswaraiah, M. VenkatRatnam, B.V. Krishna Murthy, A. Guharay and S. VijayaBhaskaraRao, J. Atmos. Sol. Terr. Phys., 105–106, 1–7, 2013 (*Citations*: 1).
371. SODAR observations of inertia-gravity waves in the atmospheric boundary layer during the passage of tropical cyclone, K. Niranjankumar, Ch. K. Rao, A. Sandeep and T. N. Rao, Atmos. Sci. Lett., DOI:10.1002/asl2.478, 2013 (*Citations*: 1).
372. Upper tropospheric water vapour variability over tropical latitudes observed using radiosonde and satellite measurements, GhouseBasha, M. VenkatRatnam and B.V. Krishna Murthy, J. Earth Sys. Sci., 122, 6, 1583-1591, 2013 (*Citations*: 1).
373. Validation study on Jason-2 rain flag and rain rate estimation over North Indian Ocean, M. Thithonis and A. Jayaraman, IEEE Geosci. Rem. Sens. Lett. 10, 6, 1537-1541, Doi: 10.1109/ LGRS.2013.2261457, 2013 (*Citations: Nil*).
374. Wavelet transform method for deriving atmospheric boundary layer height from lidar signals, R. Paleti, Y. Bhavani Kumar, T. Krishna Chaitanya, Int. J. Engg. Tech., 5, 1465 – 1473, 2013 (*Citations: Nil*) .
375. Zonal Velocity of the Equatorial Plasma Bubble over Kolhapur, Nade, D. P., A. K. Sharma, S. S. Nikte, P. T. Patil, R. N. Ghodpage, M. V. Rokade, S. Gurubaran, A. Taori and Y. Sahai, Ann. Geophys., 31, 2077–2084, doi:10.5194/angeo-31-2077-2013, 2013 (*Citations*: 3).
376. Airglow measurements of wave damping at upper mesospheric altitudes over a low latitude station in India, A. Taori and V. Kamalakar, Ind. J. Radio & Space Phys., 42, 5, 371 – 379, 2013 (*Citations*: 1).
377. Detection of long range transport of aerosols with elevated layers over high altitude station in the central Himalayas: A case study on 22 and 24 March 2012 at ARIES, Nainital, R. Solanki, N. Singh, P. Pant, U. C. Dumka, Y. Bhavani Kumar, A. K. Srivastava, S. Bist and H. C. Chandola, Ind. J. Radio & Space Phys., 42, 332 – 339, 2013 (*Citations*: 1).
378. Stratospheric ozone variations over Gadanki (13.5°N, 79.2°E) during January-February 2012 and their relationship with meridional transport near Indian sector, S. Sridharan and M. Suresh, Ind. J. Radio & Space Phys., 42, 356-363, 2013 (*Citations*: 1).
379. Validation of humidity profiles obtained from SAPHIR, on-board Megha-Tropiques, T. N. Rao, K. Sunilumar and A. Jayaraman, Curr. Sci., 104, 1635-1642, 2013 (*Citations: Nil*).
380. Radio Acoustic Sounding System (RASS) - Receiver architectures and practical aspects, T. V. Chandrasekar Sarma and T. Tsuda, Journal of Innovation in Electronics and Communication, 3, 1-5, 2013 (*Citations: Nil*).

2014

381. Adaptive neuro fuzzy inference system for profiling of the atmosphere, K. Ramesh, A. P. Kesarkar, J. Bhate, M. VenkatRatnam and A. Jayaraman, Atmos. Meas. Tech. Discuss., 7, 2715-2736, 2014 (*Citations: Nil*).
382. Assessment of GPS Radiosonde Descent Data, M. VenkatRatnam, N. Pravallika, S. Ravindrababu, GhouseBasha, M. Pramitha and B.V. Krishna Murthy, Atmos. Meas. Tech., 7, 1011-1025, 2014 (*Citations*: 4).
383. Comparative anatomy of the day- and night-time radar echoes from the 130–170 km region of the low latitude ionosphere, A.K. Patra and P. PavanChaitanya, J. Adv. Space Res. (online), http://dx.doi.org/10.1016/j.asr.2013.07.046, 2014 (*Citations: Nil*).
384. Dominance of chemical heating over dynamics in the formation of a few large mesospheric inversion layer events during January-February 2011, K. Ramesh, S. Sridharan and S. VijayaBhaskaraRao, J. Geophys. Res., DOI: 10.1002/jgra.50379, 2014 (*Citations*: 2).
385. E-region radar echoes from low-latitude field aligned irregularities due to gravity waves and tides: A case study using radar, lidar and radiosonde observations and simulations, S. Sridharan and M. Sandhya, J. Geophys. Res., DOI: 10.1002/2013JA019273, 2014 (*Citations: Nil*).
386. Estimation of the mixed layer height over a high altitude site in Central Himalayan region by using Doppler LIDAR, K. K. Shukla, D.V. Phanikumar, Rob K Newsom, K. Niranjan Kumar, M. VenkatRatnam, M Naja and Narendra Singh, J. Atmos. Sol. Terr. Phys., 109, 48-53, 2014 (*Citations*: 1).
387. Global Morphology of Convection Indices Observed Using COSMIC GPS RO Satellite Measurements, Y. DurgaSanthi, M. VenkatRatnam, S. K. Dhaka and S. VijayabhaskaraRao, Atmos. Res., 137, 205-215, 2014 (*Citations: Nil*).
388. Lidar Investigations on the optical and dynamical properties of the cirrus clouds in the UTLS region at a tropical station Gadanki, India (13.5ºN, 79.2ºE), V. Krishnakumar, M. V. Satyanarayana, S. R. Radhakrishnan, Reji K. Dhaman, Glory S. Jayeshlal, Gopinathan Nair S. Motty, V. P. MahadevanPillai, K. Raghunath, M. VenkatRatnam, D. R. Rao and P. Sudhakar, J. App. Rem. Sen., 8, 2014 (*Citations: Nil*).
389. Long-term Trends Observed in the Middle Atmosphere Temperatures Using Ground Based LIDARs and Satellite Borne Measurements, P. Kishore, M. VenkatRatnam, I. Velicogna, V. Sivakumar, H. Bencherif, B. R. Clemesha, D. M. Simonich, P. P. Batista and G. Beig, Ann. Geophys., 32, 301-317, 2014 (*Citations: Nil*).
390. Measurements of equatorial plasma depletion velocity using 630nm airglow imaging over a low-latitude Indian station, A. Taori and A. Sindhya, J. Geophys. Res., 119, 1-6, aoi:10.1002/ 2013JA019465, 2014 (*Citations*: 3).
391. Observational relations between potential vorticity intrusions and premonsoon rainfall over Indian sector, M. Sandhya and S. Sridharan, Atmos. Res., 137, 80-90, 2014 (*Citations*: 4).
392. Performance evaluation of PBL and cumulus parameterization schemes of WRF ARW model in simulating severe thunderstorm events over Gadanki MST radar facility –

case study, M. Srikanth, A.N.V. Satyanarayana and T. N. Rao, Atmos. Res., 1-17, 2014 (*Citations*: 4).

393. Properties of rainfall in a tropical volcanic island deduced from UHF wind profiler measurements, A. Rechou, T. N. Rao, O. Bousquet, M. Plu and R. Decoupes, Atmos. Meas. Tech., 7, 1-10, 2014 (*Citations: Nil*).
394. Quite time short-period and day-to-day variations in ExB drift studied using 150 km radar echoes from Gadanki, P. Pavan Chaitanya, A. K. Patra and S. V. B. Rao, J. Geophys. Res., 119, doi. 10.1002/2013JA019668, 2014 (*Citations: Nil*).
395. Signatures of Rossby Wave Modulation in the Aerosol Optical Depth over Central Himalayas, D. V. Phanikumar, K. Niranjan Kumar, K. K. Shukla, M. VenkatRatnam and M.Naja, Ann. Geophys., 32, 175-180, 2014 (*Citations: Nil*).
396. Deriving aerosol scattering ratio using range resolved lidar ratio, R.K. Dhaman, V Krishnakumar, V. P. M. Pillai, M. Satyanarayana and K. Raghunath, Pramana – J. Phys., 82, 391-395, 2014 (*Citations: Nil*)
397. VHF radar observations of mesospheric echoes and their relationship with thermal structure over Gadanki (13.5°N, 79.2°E), S. Sridharan, M. Suresh and K. Ramesh, Ind. J. Radio & Space Phys., 42, 364-370, 2013 (*Citations: Nil*).
398. Airglow measurements of mesospheric wave structures and thermal gradient variability, over a low-latitude Indian station, A. Taori, Curr. Sci., 106, 4, 542 – 551, 2014 (*Citations: Nil*).
399. Atmospheric CO2 Variations in Two Contrasting Environmental Sites Over India, Neerja Sharma, V. K. Dhadhwal, P. Mahesh, K. Mallikarjun, M.M. Ali, H. Gadhavi, Y. Kant and Anand Sharma, J. Air Soil Water Res., 61-68, doi: 10.4137/aswr.s13987, 2014 (*Citations: Nil*).
400. Design and fabrication of crossed- Yagi antennae for dual frequency satellite signal reception at ground, N. Dashora, K. Venkatramana and S.V.B. Rao, Ind. J.Radio & Space Physics, 43, 2014 (*Citations: Nil*).
401. Large scale anomalous temperature and wind variations in the lower and middle atmospheres during the solar eclipse of 15 January 2010, T. K. Ramkumar, PriyankaGhosh, K. Krishna Reddy, K. Niranjan Kumar, S. Balaji Kumar, A. Hari Krishna Reddy, M. Venkatrami Reddy and S. B. Surendra Prasad, Ind. J.Radio & Space Phys., 43, 75-82, 2014 (*Citations: Nil*).
402. Lower and middle atmospheric responses to the 22 July 2009 total solar eclipse, M. VenkatRatnam, GhouseBasha, S. Eswariah and M. Roja Raman, Ind. J.Radio & SpacePhys., 43, 91-102, 2014 (*Citations: Nil*).
403. Modulation of thermal structure in the upper troposphere and lower stratosphere (UTLS) region by inertia-gravity waves: A case study inferred from simultaneous MST radar and GPS sonde observations, Siddarth Shankar Das, K. K. Kumar, K. N. Uma, M.VenkatRatnam, A. K. Patra, S. K. Das, A. K. Ghosh and A. R. Jain, Ind. J.Radio & SpacePhys., 43, 11-23, 2014 (*Citations: Nil*).
404. A comprehensive investigation on afternoon-evening transition of the atmospheric boundary layer over a tropical rural site, A. Sandeep, T. N. Rao and S. V. B. Rao, Atmos. Chem. Phys. Diss., 14, 1-32, 2014 (*Citations: Nil*).
405. Infrequent occurrence of new particle formation at a semi-rural location, Gadanki, in tropical Southern India by V. P. Kanawade, S. Shika, C. Pohlker, D. Rose, M. N. S. Suman, H. Gadhavi, A. Kumar, S. M. S. Nagendra, R. Ravi Krishna, H. Yu, L. Sahu, A.

Jayaraman, M. O. Andreae, U. Poschl and S. Gunthe, Atmos. Env., 2014, doi: 10.1016/j.atmosenv.2014.05.046 (*Citations*: 2).

406. Airglow Measurements of Gravity Wave Propagation and Damping over Kolhapur (16.5^{o}N, 74.2^{o}E), R. N. Ghodpage, A. Taori, P.T. Patil, S. Gurubaran, A. K. Sharma, S. Nikte and D. Nade, J. Geophys.Res., doi: 10.1155/2014JA514937, 2014 (*Citations*: 1).
407. Morphology of the vertical structure of precipitation over India and adjoining oceans based on long-term measurements of TRMM PR, K. Saikranthi, T. N. Rao, B. Radhakrishna and S.V. B. Rao, J. Geophys. Res., doi:10.1002/2014JD0774, 2014 (*Citations*: 2).
408. Causative mechanisms for the occurrence of a triple layered mesospheric inversion event over low latitudes, K. Ramesh, K, S. Sridharan and S. Vijaya Bhaskara Rao, J. Geophys. Res., 119, 3930–3943, doi:10.1002/2013JA019750, 2014 (*Citations: Nil*).
409. First results on low-latitude E and F region irregularities obtained using the Gadanki Ionospheric Radar Interferometer (GIRI), A.K. Patra, P Srinivasulu, P. Pavan Chaitanya, M. Durga Rao and A. Jayaraman, J. Geophys. Res., 119, 10,276–10,293, doi:10.1002/2014JA020604, 2014 (*Citations*: 1).
410. Solar rotation effects on the Martian ionosphere, N. Venkateswara Rao, N. Balan and A. K. Patra, J. Geophys. Res., 119, 6612–6622, doi:10.1002/2014JA019894, 2014 (*Citations*: 1).
411. Ionospheric variability over Indian low latitude linked with the 2009 sudden stratospheric warming, A. K. Patra, P. Pavan Chaitanya, S. Sripathi and S. Alex, J. Geophys. Res., 119, 4044–4061, doi:10.1002/2014JA019847, 2014 (*Citations*: 2).
412. Parallel plate capacitor analogy of equatorial plasma bubble and associated fringe fields with implications to equatorial valley region irregularities, S. Mukherjee and A. K. Patra, J. Geophys. Res., 119, doi:10.1002/2014JA020113, 2014 (*Citations*: 2).
413. Vertical ExB drifts from radar and C/NOFS observations in the Indian and Indonesian sectors: Consistency of observations and model, A. K. Patra, P. Pavan Chaitanya, Y. Otsuka, T. Yokoyama, M. Yamamoto, R. A. Stoneback and R. A. Heelis, J. Geophys. Res., 119, 3777–3788, doi:10.1002/2013JA019732, 2014 (*Citations: Nil*).
414. Advanced meteor radar installed at Tirupati: System details and comparison with different radars, Rao S. V. B., S. Eswaraiah, M. Venkat Ratnam, E. Kosalendra, K. Kishore Kumar, S. Sathish Kumar, P. T. Patil and S. Gurubaran, J. Geophys. Res. Atmos., 119, doi:10.1002/2014JD021781, 2014 (*Citations: Nil*).
415. Role of Coarse and Fine Mode Aerosols in MODIS AOD Retrieval: a case study over southern India by M. N. S. Suman, H. Gadhavi, V. Ravi Kiran, A. Jayaraman and S. V. B. Rao, Atmospheric Measurement Techniques, 2014, doi: 10.5194/amt-7-907-2014 (*Citations*: 3).
416. Differences in atmospheric boundary layer characteristics between wet and dry episodes of the Indian summer monsoon, Sandeep A, T. N. Rao, C.N. Ramkiran and S.V.B. Rao, Boundary-Layer Meteorol., 153, 217-236, 2014 (*Citations*: 4) .
417. Evaluation of atmospheric turbulence, energy exchanges and structure of convective cores during occurrence of mesoscale convective systems using MST radar facility at Gadanki, A.N.V. Satyanarayana, S Sultana, T. N. Rao and S. Satheesh Kumar, Atmospheric Research, 143, 198-215, 2014 (*Citations*: 2).
418. Vertical temperature wave number spectra of the Martian lower atmosphere, Priyanka Ghosh and T. K. Ramkumar, Atmos. Sci. Let., DOI: 10.1002/asl2.545, 2014 (*Citations: Nil*).

419. An objective criterion for the identification of breaks in Indian summer monsoon rainfall, U. Umakanth, A. P. Kesarkar, T. N. Rao and S.V.B. Rao, Atmos. Sci. Lett., doi:10.1002/asl2.536, 2014 (*Citations: Nil*).
420. Improved performance over time of integration in momentum flux estimation using postset beam steering technique, V.K. Anandan, J. Shridhar Kumar, V.N. Sureshbabu, T. N. Rao, M. Purnachandra Rao and T. Tsuda, J. Atmos. Sol. Terr. Phys., 120, 132-142, 2014 (*Citations: Nil*).
421. Intercomparison of various SA techniques on wind estimation using multi-receiver phased array radar, J Shridhar Kumar, V.K. Anandan, V.N. Sureshbabu, T. N. Rao, M. Purnachandra Rao, T. Tsuda, Atmos. Sol. Terr. Phys., 118, 25-34, 2014 (*Citations: Nil*).
422. A brief overview on the special issue on CAWSES-India Phase II program, D. Pallam Raju, S. Gurubaran and M. Venkat Ratnam, J. Atmos. Sol. Terr. Phys., 121, 141–1144, 2014 (*Citations: Nil*).
423. Solar cycle effects on Indian summer monsoon dynamics, M. Venkat Ratnam, Y. Durga Santhi, P. Kishore, S. Vijaya Bhaskara Rao, J. Atmos. Sol. Terr. Phys., 121, 145–156 , 2014 (*Citations*: 1).
424. Diurnal tide in the low-latitude troposphere and stratosphere: Long-term trends and role of the extended solar minimum, M. Venkat Ratnam, N. VenkateswaraRao, C. Vedavathi, B.V.Krishna Murthy, S. Vijaya BhaskaraRao, J. Atmos. Sol. Terr. Phys., 121, 168-176, 2014 (*Citations*: 1).
425. Detection of tropopause altitude using Indian MST radar data and comparison with simultaneous radiosonde observations, S. Ravindrababu, M. Venkat Ratnam, S.V. Sunil kumar, K. Parameswaran, B.V. Krishna Murthy, J. Atmos. Sol. Terr. Phys., 121, 240-247, 2014 (*Citations*: 1).
426. Tropical Tropopause Dynamics (TTD) Campaigns over Indian region: An Overview. M. Venkat Ratnam, S. V. Sunil kumar, K. Parameswaran, B. V. Krishna Murthy, Geetha Ramkumar, K Rajeev, Ghouse Basha, S. Ravindra Babu, M. Muhsin, Manoj Kumar Mishra, A. Hemanth Kumar, S. T. Akhil Raj and M. Pramitha, J. Atmos. Sol. Terr. Phys., 121, 229-239, 2014, 2014 (*Citations*: 7).
427. Characteristics of cirrus clouds and tropical tropopause layer: Seasonal variation and long-term trends, Amit Kumar Pandit, Harish Gadhavi, M. Venkat Ratnam, A. Jayaraman, K. Raghunath. S.Vijaya Bhaskara Rao, J. Atmos. Sol. Terr. Phys., 121, 248-256, 2014 (*Citations*: 2).
428. Long-term variabilities and tendencies in zonal mean TIMED–SABER ozone and temperature in the middle atmosphere at 10–15°N, O. Nath and S. Sridharan, J. Atmos. Sol.Terr. Phys., 11/2014; 120:1–8. DOI: 10.1016/j.jastp.2014.08.010, 2014 (*Citations: Nil*).
429. Equatorial stratospheric thermal structure and ozone variations during the sudden stratospheric warming of 2013, O. Nath, S. Sridharan and H. Gadhavi, J. Atmos. Sol. Terr. Phys.,11/2014; DOI: 10.1016/j.jastp.2014.11.003, 2014 (*Citations: Nil*)
430. Simultaneous optical measurements of equatorial plasma bubble (EPB) from Kolhapur (16.8°N, 74.2°E) and Gadanki (13.5°N, 79.2°E), R.N. Ghodpage, A. Taori, P.T. Patil, S. Gurubaran, S. Sripathi, S. Banola and A.K. Sharma, J. Atmos. Sol. Terr. Phys., doi: 10.1016/j.jastp.2014.05.008, 2014 (*Citations*: 4).

431. Scattering cross section of mesospheric echoes and turbulence parameters from Gadanki radar observations, D. Selvaraj, A.K. Patra, H. Chandra, H. S. S. Sinha and U. Das, J. Atmos. Solar-Terr. Phys., 119,162–172, 2014 (*Citations*: 1).
432. The occurrence altitudes of middle atmospheric temperature inversions and mesopause over low-latitude Indian sector, M. Sivakandan, D. Kapasi and A. Taori, Ann. Geophy., 32, 967-974, doi:10.5194/angeocom-32-1-2014, 2014 (*Citations: Nil*).
433. Study of Ozone and NO_2 over Gadanki - a rural site in South India, K. Renuka, H. S. Gadhavi, A. Jayaraman, S. Lal, M. Naja and S. V. B. Rao, Journal of Atmospheric Chemistry, 2014, doi: 10.1007/s10874-014-9284-y, 2014 (*Citations*: 2).
434. Recent advances in equatorial, low- and mid-latitude mesosphere, thermosphere - ionosphere system studies, A. Taori and P. R. Fagundes, Adv. Space Res., 54, doi: 10.1016/j.asr.2014.05.001, 2014 (*Citations: Nil*).
435. Response of the mid-latitude D-region ionosphere to the total solar eclipse of 22 July 2009 studied using VLF signals in South Korean peninsula, D. V. Phanikumar, Y.-S. Kwak, A.K. Patra, A. K. Maurya, R. Singh, S.-M. Park, Adv. Space Res., 54, 961–968, 2014 (*Citations*: 2).
436. Wind Motions around the Tropical Cirrus Using Simultaneous Radar and Lidar Observations over Gadanki (13.45° N, 79.18° E), India, C. Dhanunjay Rao, M.A. Srinivasan, M. Krishnaiah, Y. Bhavani Kumar, and S.V.B Rao, Int. J. Geosci., 5, 1241-1253, 2014 (*Citations: Nil*).
437. Rayleigh lidar observations of mesospheric inversion layers over Gadanki and their relationship with gravity wave activity, K. Ramesh, S. Sridharan, S. Vijaya Bhaskara Rao, K. Raghunath, Y. Bhavani Kumar, Ind. J. Radio & Space Phy., 43, 83-90, 2014 (*Citations: Nil*).
438. Lidar signal denosing methods- application to NARL Rayleigh lidar , M. Sarvani, K. Raghunath, S. Vijaya Bhaskara Rao, Journal of Optics, DOI 10.1007/s12596-015-0247-8, 2014 (*Citations: Nil*).
439. Wind Power Density Analysis for Micro-Scale Wind Turbines, Karthick Kumar Reddy, S. Venkatramana Reddy,T. K. Ramkumar, B. Sarojamma, The Int. J. Eng. Sci. Inven., 3, 53-60, 2014 (*Citations: Nil*).
440. Evaluation of black carbon emission inventories using a Lagrangian dispersion model – a case study over southern India by H. S. Gadhavi, K. Renuka, V. Ravi Kiran, A. Jayaraman, A. Stohl, Z. Klimont and G. Beig, Atmos. Chem. Phys. Discuss., 14, 26903-26938, 2014 (*Citations*: 1).

2015

441. Vertical and latitudinal variation of the Inter-tropical Convergence Zone derived using GPS Radio Occultation measurements, Ghouse Basha, P. Kishore, M. Venkat Ratnam, I. Velicogna and T. Sutterly, Rem. Sense. Env., 2015 (*Citations: Nil*).
442. Evidence for tropospheric wind shear excitation of high phase-speed gravity waves reaching the mesosphere using the ray-tracing technique, M. Pramitha, M. Venkat Ratnam, A. Taori, B. V. Krishna Murthy, D. Pallamraju and S. Vijaya Bhaskar Rao, Atmos. Chem. Phys., 15, 15, 2709–2721, 2015 (*Citations*: 1).
443. Role of vertical structure of cloud microphysical properties on cloud radiative forcing over the Asian monsoon region by V. Ravi Kiran, M. Rajeevan, H. Gadhavi, S. V.

B. Rao and A. Jayaraman, Cli. Dyn., 2015, doi: 10.1007/s00382-015-2542-0 (*Citations: Nil*).

444. Multi-instrument investigation of a mesospheric gravity wave event absorbed into background, M. Sivakandan, A. Taori, S. Sathishkumar and A. Jayaraman, J. Geophys. Res., 33, doi: 10.1002/2014JA020896, 2015 (*Citations: Nil*).
445. Adaptive neuro fuzzy interference system for profiling of the atmosphere, K. Ramesh, A.P. Kesarkar, J. Bhate, M. Venkat Ratnam and A.Jayaraman, Atmos. Meas. Tech., 8, 369–384, 2015 (*Citations: Nil*).
446. A novel approach for the extraction of cloud motion vectors using airglow imager measurements, S. Satheesh Kumar, T. Narayana Rao and A. Taori, Atmos. Meas. Tech. Discuss., 8, 2657–2682, doi:10.5194/amtd-8-2657-2015, 2015 (*Citations: Nil*).
447. A case study on occurrence of an unusual structure in the sodium layer over Gadanki, India, Sarkhel, S., J. D. Mathews, S. Raizada, R. Sekar, D. Chakrabarty, A. Guharay, G. Jee, J.-H. Kim, R. B. Kerr, G. Ramkumar, S. Sridharan, Q. Wu, M. G. Mlynczak and J. M. Russell III, Earth Planets Space, 67:19, doi:10.1186/s40623-015-0183-5, 2015 (*Citations*: 2).
448. Role of deep convection on the tropical tropopause characteristics at sub-daily scales over the South India monsoon region, A. Hemanth Kumar, M. Venkat Ratnam, S. V. Sunil Kumar, K. Parameswaran, B. V. Krishna Murthy, J. Atmos. Res., http://dx.doi.org/10.1016/j.atmosres.2015.03.012, 2015 (*Citations: Nil*).
449. Stable isotopic differences between summer and winter monsoon rains over southern India, R. Srivastava, R. Ramesh and T. N. Rao, J. Atmos. Chem., doi:10.1007/ s10874- 015-9297-1, 2015 (*Citations: Nil*).
450. Radiative implication of a haze event over Eastern India, Subin Jose, Biswadip Gharai, Y. Bhavani Kumar, P.V.N Rao, Atmos. Poll. Res., 6, 138-146, 2015 (*Citations: Nil*).
451. On the vertical wavelength estimates using the Krassovsky parameters of OH airglow monitoring, R. N. Ghodpage, A. Taori, P. T. Patil, Devendraa Siingh, S. Gurubaran and A. K. Sharma, Curr. Sci., 108, 7, 2015 (*Citations: Nil*).
452. Evidence of meteoroid fragmentation is specular trail echoes observed using Gadanki MST radar, A. Patel, A. Malhotra, A. K. Patra, T. R. Prasad and J. D. Mathews, Earth Moon Planets, 114, 89-99, doi 10.1007/s11038-014-9456-4, 2015 (*Citations: Nil*).
453. Characteristics of low-latitude TEC during solar cycles 23 and 24 using global ionospheric maps (GIMs) over Indian sector Dashora, N. and S. Suresh, J. Geophys. Res., 120, 5176–5193, doi:10.1002/2014JA020559, 2015 (*Citations: Nil*).
454. Probing the possible trigger mechanisms of an equatorial plasma bubble event based on multi-station optical data, A. Taori, N. Parihar, R. Ghodpage, N. Dashora, S. Sripathi, E. A. Kherani and P. T. Patil, J. Geophy. Res., doi:10.1002/2015JA021541, 2015 (*Citations: Nil*).
455. Revisiting the Airglow Image Analysis to Obtain and Visual Representation of the Spatial and Temporal Information', M. Sivakandan and A. Taori, Earth Science India, eISSN: 0974-8350, 8 (III), July 2015, 50–60, 2015 (*Citations: Nil*).
456. New image measurements of the gravity wave propagation characteristics from a low latitude Indian station, M. Sivakandan, A. Taori and K. Niranjan, Atmos. Meas. Tech. Discuss., 8, 8231–8255, doi:10.5194/amtd-8-8231-2015, 2015 (*Citations: Nil*).

457. An investigation of long-distance propagation of gravity waves under CAWSES India Phase II Programme, N. Parihar and A. Taori, Ann. Geophy., 33, 547–560, doi:10.5194/angeo-33-547-2015, 2015 (*Citations: Nil*).
458. Ionospheric variations over Indian low latitude close to the equator and comparison with IRI-2012, P. Pavan Chaitanya, A. K. Patra, N. Balan and S. V. B. Rao, Ann. Geophys., 33, 997–1006, 2015 (*Citations: Nil*).
459. Fringe field dynamics over equatorial and low-latitude ionosphere: a three-dimensional perspective, E.A. Kherani and A.K. Patra, J. Geophys. Res., 120, doi: 10.1002 /2015JA021438, 2015 (*Citations: Nil*).
460. Influence of tropical cyclones on tropospheric ozone: possible implication, S. S. Das, M. V. Ratnam, K. N. Uma, K. V. Subrahmanyam, I. A. Girach, A. K. Patra, S Aneesh, K. V. Suneeth, K. K. Kumar, A. P. Kesarkar, S. Sijikumar and G. Ramkumar, Atmos. Chem. Phys. Discuss., 15, 19305-19323, doi:10.5194/acpd-15-19305-2015, 2015 (*Citations: Nil*).
461. Assessment of small-scale variability of rainfall and multisatellite precipitation estimates using a meso-rain gauge network measurements from southern peninsular India, Sunilkumar, K., T. N. Rao and S. Satheesh kumar, Hydro. Earth Sys. Sci. Discuss., hess-2015-387, 2015 (*Citations: Nil*).
462. Comprehensive evaluation of multisatellite precipitation estimates over India using gridded rainfall data, Sunilkumar K., T. N. Rao, K. Saikranthi and M. P. Rao, J. Geophy. Res., doi:10.1002/2015JD023437, 2015 (*Citations: Nil*).
463. A comprehensive investigation on afternoon transition of the atmospheric boundary layer over a tropical rural site, Sandeep, A., T. N. Rao and S V. B. Rao, Atmos. Chem. Phys., 15, 7605-7617, 2015 (*Citations: Nil*).
464. Review and testing analysis of Moupfouma rain rate model for southern India, J. Atmos. Solar-Terr. Phys., Chandrika, P., S. V. B. Rao, N V P Kirankumar and T. N. Rao, 132, 33-36, 2015 (*Citations: Nil*).
465. Validation of empirical rainrate models over a tropical coastal station, Chandrika, P., S V. B. Rao, N V P Kirankumar and T. N. Rao, IEEE Ant. and Wireless Pro. Lett., 99, DOI:10.1109/LAWP.2015.2469721, 2015 (*Citations: Nil*).
466. Observational evidence of the influence of Antarctic stratospheric ozone variability on middle atmosphere dynamics, Venkateswara Rao, N., P. J. Espy, R. E. Hibbins, D. C. Fritts and A. J. Kavanagh, Geophys. Res. Lett., 42, doi:10.1002/2015GL065432, 2015 (*Citations: Nil*).
467. Effect of tropical cyclones on the tropical tropopause parameters observed using COSMIC GPS RO data, S. RavindraBabu, M. VenkatRatnam, G. Basha, B. V. Krishnamurthy and B. Venkateswararao, Atmos. Chem. Phys., 15, 10239–10249, 2015 (*Citations: Nil*).
468. Characteristics of turbulence in the troposphere and lower stratosphere over the Indian Peninsula, S.V. Sunilkumar, M. Muhsin, K. Parameswaran, M. VenkatRatnam, GeethaRamkumar, K.Rajeev, B. V. Krishna Murthy, K. V. SambhuNamboodiri, K.V. Subrahmanyam, K. Kishore Kumar, Siddarth Shankar Das, J. Atmos. Sol. Terr. Phys., 133, 36-53, 2015 (*Citations: Nil*).
469. Vertical distribution of ozone over a tropical station: Seasonal variation and comparison with satellite (MLS, SABER) and ERA-Interim products, S.T. Akhil Raj, M. VenkatRatnam, D. Narayana Rao, B.V. Krishna Murthy, Atmos. Env., 116, 281-292, 2015 (*Citations: Nil*).

470. Short wave aerosol radiative forcing estimates over a semi urban coastal environment in south-east India and validation with surface flux measurements, K. Aruna, T.V. Lakshmi Kumar, B.V. Krishna Murthy, S. Suresh Babu, M. VenkatRatnam, D. Narayana Rao, Atmos. Env., (In Press), 2015 (*Citations: Nil*).
471. Evaluation of black carbon emission inventories using a Lagrangian dispersion model – a case study over southern India, H.S. Gadhavi, K. Renuka, V. Ravi Kiran, A. Jayaraman, A. Stohl, Z. Klimont and G. Beig. Atmos. Chem. Phys., 15, 1447–1461, doi:10.5194/acp-15-1447-2015, 2015 (*Citations*: 5).
472. 16 year climatology of cirrus clouds over a tropical station in southern India using ground and space-based lidar observations, Pandit, A. K., H. S. Gadhavi, M. Venkat Ratnam, K. Raghunath, S. V. B. Rao and A. Jayaraman, Atmos. Chem. Phys. Discuss., 15, 15791–15830, doi:10.5194/acpd-15-15791-2015 (*Citations: Nil*)
473. Role of vertical structure of cloud microphysical properties on cloud radiative forcing over the Asian monsoon region, Ravi Kiran, V., M. Rajeevan, H. Gadhavi, Rao and A. Jayaraman, Cli. Dyn., 1–15, doi:10.1007/s00382-015-2542-0, 2015 (*Citations: Nil*).
474. Tropical upper tropospheric ozone enhancements due to potential vorticity intrusions over Indian sector, Sandhya, M., S. Sridharan, M. Indira Devi and H. Gadhavi. J. Atmos. Sol.Terr. Phy., 132 147–152, doi:10.1016/j.jastp.2015.07.014, 2015 (*Citations: Nil*).
475. Study of thermal structure differences from coordinated lidar observations over Mt. Abu (24.5° N, 72.7° E) and Gadanki (13.5° N, 79.2° E), S. Sharma, H. Chandra, S. Lal, Y. B. Acharya, A. Jayaraman, H. Gadhavi, S. Sridharan and S. Chandra, Earth, Planets and Space 67, doi:10.1186/s40623-015-0258-3, 2015 (*Citations: Nil*).
476. Equatorial middle atmospheric chemical composition changes during sudden stratospheric warming events, O. Nath, S. Sridharan, Atmos. Chem. Phy. Discuss., 15, 23969-23988, 2015 (*Citations: Nil*).
477. Tropical upper tropospheric humidity variations due to potential vorticity intrusions, M. Sandhya, S. Sridharan and M. Indira Devi, Ann. Geophy., 33, 1081-1089, 2015 (*Citations: Nil*).
478. A case study on occurrence of an unusual structure in the sodium layer over Gadanki, India, Sarkhel, S., J. D. Mathews, S. Raizada, R. Sekar, D. Chakrabarty, A. Guharay, G. Jee, J.-H. Kim, R.B. Kerr, G. Ramkumar, S. Sridharan, Q. Wu, M. G. Mlynczak and J.M. Russell IIIA, Earth, Planets and Space, 67:19, doi:10.1186/s40623-015-0183-5, 2015 (*Citations*: 2).
479. A case study of formation and maintenance of a lower stratospheric cirrus cloud over the tropics Sandhya, M., S. Sridharan, M. Indira Devi, K. Niranjan and A. Jayaraman, AnGeo Comm., 33, 599–608, 2015 (*Citations: Nil*).
480. Influence of solar cycle and chemistry on tropical (10°N–15°N) mesopause variabilities, Ramesh, K., S. Sridharan and S. Vijaya Bhaskara Rao, J. Geophys. Res., 120, 4038–4051, doi:10.1002/2014JA020930, 2015 (*Citations: Nil*).
481. Tropical response to extratropical eastward propagating waves, S. Sridharan and M. Sandhya, Atmos. Chem. Phys. Discuss., 15, 15137-15153, doi:10.5194/acpd-15-15137-2015, 2015 (*Citations: Nil*).
482. Application of finite difference technique to Raman lidar signals to derive the altitude profiles of atmospheric aerosol extinction, S. Purusotham, Y. Bhavani Kumar, Int. J. Engg. Tech., 7, 857-867, 2015 (*Citations: Nil*).

483. A novel approach for the extraction of cloud motion vectors using airglow imager measurements, S. Satheesh Kumar, T. Narayana Rao and A. Taori, Atmos. Meas. Tech., 8, 3893-3901, doi: 10.5194/amt-8-3893-2015, 2015 (*Citations: Nil*).

Total number of publications : 483
Total number of *Citations* : 4306

Note: Citations are extracted from Google Scholar as on 30 September 2015.